THE DEPLOYMENT OF EMERGENCY SERVICES

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PREFACE

This report provides a nontechnical summary of the models and methods that have been developed at The New York City-Rand Institute to assist large and small emergency service agencies to analyze problems associated with the deployment of emergency vehicles such as police cars, fire engines, and ambulances. The models have been tested for applicability, usefulness, and transferability under Contract H-2164 with the Office of Policy Development and Research of the U.S. Department of Housing and Urban Development. Each of the models has been used in analyzing the deployment problems of at least one emergency service agency. Descriptions of many of these tests have been published as case studies. A brief description of each case study is included.

The report is designed for the use of planning personnel and analysts of emergency service agencies and other local government agencies. It is a guide to some of the tools that are available for setting deployment objectives, measuring the performance of their agencies, and determining new deployment policies. The report also indicates where additional information about the tools and techniques can be obtained. A conscious attempt has been made to avoid the use of technical descriptions and mathematical equations that form the basis for many of the models. Those interested in the technical details should read the appropriate references.

The reader is assumed to be familiar with the deployment problems of emergency service agencies. A good introduction to police deployment problems is *Patrol Allocation Methodology for Police Departments*, by Jan Chaiken. Fire deployment problems are discussed in *Deployment Methodology for Fire Departments*, by Jan Chaiken, Edward Ignall, and Warren Walker. Both reports are reviewed here and are included in the Bibliography at the end of the report. Further information on any of the material described in this report can be obtained by writing to the appropriate address shown in the Appendix.

SUMMARY

Over the past several years many new techniques for emergency service deployment analysis have been developed at The New York City-Rand Institute. These methods can be used for the comparative evaluation of fire station locations, for determining the number of patrol cars or ambulances an agency should have on duty at various times of day, for designing patrol beats for police cars, and for related issues. Much of the developmental work was sponsored by New York City, but some was sponsored by the National Science Foundation (NSF) and the U.S. Department of Housing and Urban Development (HUD).

After the developmental work was completed, HUD and two municipal governments (Trenton, New Jersey, and Yonkers, New York) sponsored field tests of the methods, so that in their final form they represent the experienced gained in many cities. Other cities that cooperated with HUD-sponsored work were Denver, Jersey City, New Haven, Tacoma, Washington, and Wilmington. In addition, over 20 cities in the U.S. and other countries have adopted one or more of the models described in this *Guide* without any direct assistance from the Institute or HUD.

The HUD-sponsored work led to the publication of more than 30 reports over a period of two and one-half years. This report has been written to provide a single unified reference to all of this material in a form useful to analysts and planners who might be interested in deployment analysis.

An emergency service agency anticipating any type of deployment analysis should assign a planner having some technical skills and familiarity with the agency's data-processing capabilities to review the various approaches that can be taken, their feasibility, cost, and potential benefits. One of the two methodology reports prepared by The New York City-Rand Institute will assist the planner in this review:

- *Deployment Methodology for Fire Departments*, Jan Chaiken, Edward Ignall, and Warren Walker, The New York City-Rand Institute, R-1853-HUD, September 1975;
- *Allocation Methodology for Police Departments*, Jan Chaiken, The New York City-Rand Institute, R-1852-HUD, September 1975.

These reports describe many different computer-based models for deployment analysis, whether developed by The New York City-Rand Institute or not. They also contain references to help the planner locate more information about the models that appear relevant to his agency's concerns.

If the planner finds any of The New York City-Rand Institute reports to be of potential interest, he can turn to this *Guide* for further details about the contents of each report. He will then know whether he wishes to order the reports and read them carefully. Some will help him in his initial feasibility review, while others will not be required until the agency has decided to proceed with its deployment analysis. For example, the executive summary of a deployment model provides information that can be helpful in deciding whether to purchase the computer program, whereas a report describing how one installs the program on a computer system is not needed until later.

Examples of the deployment analyses in some of the cities mentioned earlier have been written as case studies that give the planner a clear indication of the kinds of questions that were addressed, organizational arrangements that were made for conducting the analysis, the cost and length of time involved, and the benefits obtained. By consulting this *Guide*, the planner may find that one of the case studies describes a city similar to his own or one with a similar deployment problem. He can then obtain a copy of the appropriate report and prepare his own plans in light of successful and unsuccessful features of the analysis described in the case study.

After an agency selects a deployment problem as worthy of analysis, it will be necessary to form a suitable project team, to budget appropriate funds for the work, and to train the members of the team in the work they will do. One of the reports described in this *Guide* is a training course manual that provides complete lecture notes and examples of suitable visual aids and demonstrations of computer programs. Using guest lecturers, this course can be presented in three to five days. Or, the members of the project team could share the work of learning the material in the training course lecture notes. In this case, the information might be discussed in weekly meetings rather than being presented as formal lectures. The audience for the lectures should include high-ranking agency and municipal officials who will be called upon to implement the results of the analysis, as well as the staff that will carry out the work.[1]

Either before or after training has been conducted, the agency will need to purchase appropriate computer programs, together with user's manuals and installation instructions. (Purchasing the programs before the training course permits them to be demonstrated as part of the training, using a data base from an example city.) This *Guide* describes each of the deployment models according to the following format:

- A brief description of the model and how it works.
- The deployment questions that the model is designed to address.
- The data that must be obtained before the model can be used.
- The results produced by the model.
- The assumptions that were made in developing the model and the restrictions that they impose on the results.
- A summary of where the model has been used and with what results.
- The effort and cost involved in preparing the model for use in a city, the size and type of computer that must be available, and special computer languages needed.
- The approximate cost of making a single run with the model.
- A list of publications that describe the model.

This information should be adequate to determine which of the documents describing models should be obtained, but each agency will have to estimate for itself the cost and time involved in preparing the data for the model, conducting the analysis, and implementing the findings.

[1] The training course materials may also be of interest to organizations other than emergency service agencies, such as police academies, colleges, and universities

ACKNOWLEDGMENTS

The work summarized in this report represents the culmination of nearly eight years of effort devoted to improving the deployment of emergency services. This work was performed at The New York City-Rand Institute. It has been very much a team effort, with many members spending five years or more on the team. The driving force behind most of the model building was the work being done for the Fire Department of New York City under the direction of my predecessors, Edward Blum, Rae Archibald, and Arthur Swersey. Ed Blum and Jan Chaiken led the HUD-sponsored work to generalize, test, and document the models developed for New York and got the project well under way before I took it over in 1973.

In describing the models, methods, and case studies I have drawn heavily from existing reports. I therefore wish to thank the authors of those reports for the use of the material.

The testing and documentation of the models would have been impossible without the sponsorship of the Office of Policy Development and Research, U.S. Department of Housing and Urban Development, and the active cooperation, support, and encouragement of Alan Siegel and Hartley Fitts of HUD's Community Development and Management Research Division.

Although it would be impossible to give credit to everyone who has worked on the team and whose efforts have contributed to its success, I wish to thank two whose help has been invaluable and without whose prodigious efforts I could not have accomplished half of what was actually accomplished: Jan Chaiken and Ed Ignall.

CONTENTS

INTRODUCTION

Because of the financial crises being experienced by most cities, municipal service agencies are being faced with a choice between increasing their productivity and reducing service. In many cities these pressures are especially strong on emergency service agencies. They are almost all experiencing rapidly increasing demands while managerial and technological problems are mounting and costs are rising faster than the revenues needed to pay for them. As a result, cities increasingly need more effective ways of providing emergency services.

Improved effectiveness, however, has not been easy to achieve. Most emergency service agencies lean heavily, in management and operation, on a wide range of traditions and rules of thumb, many of which need to be replaced by new, scientific methods. Many of the agencies want to make the required changes, but lack the knowledge and understanding of analytical techniques that would help them to evaluate the effects of contemplated changes.

Over the past several years many new techniques for emergency service deployment analysis have been developed at The New York City-Rand Institute. Much of the developmental work was sponsored by New York City, but some was sponsored by the National Science Foundation (NSF), the U.S. Department of Housing and Urban Development (HUD), and the cities of Yonkers, New York, and Trenton, New Jersey. The primary product of this work is a collection of *models*, which are computer programs designed to help analysts devise new operating policies for their agencies and anticipate the consequences of changes before they are put into effect.

The HUD-sponsored work included: testing the Institute's deployment models in a number of cities, documenting both the tests (as case studies) and the models; developing and documenting a general methodology for using the models to analyze emergency service deployment problems; and developing and presenting (several times) a training course for teaching the fundamental ideas behind the methods and models.

This effort has led to the publication of more than 30 reports over a period of two and one-half years. This report has been written to provide a single unified guide to all of this material. It is organized to be useful to analysts and planners who might be interested in carrying out deployment analyses. The previously published reports fall into four categories: (1) documentation of the deployment models; (2) case studies of the deployment analyses performed in each of the test cities; (3) descriptions of how the models relate to each other and can be used together to analyze various deployment questions; and (4) documentation of a training course designed to teach the models and methods to emergency service agency personnel, local government administrators, and systems analysts. Each category is covered in a separate section of this report, followed by a bibliography listing all of the reports.

Persons wishing to obtain any of the publications or computer programs described in this report, or wishing to obtain additional information about the HUD-sponsored project should write to the appropriate sources listed in the appendix.

II. DEPLOYMENT MODELS

In this section we briefly describe a number of models for analyzing the deployment problems of municipal emergency services (police, fire, and ambulance). The models described cover a broad spectrum of complexity, transferability, and applicability. There is no one model that, by itself, suffices to analyze and evaluate all deployment strategies. Rather, different models are needed to address different policy issues.

Deployment issues basically fall into two broad areas: *strategic* and *tactical*. *Strategic* deployment issues involve questions of long-range planning and resource allocation, such as:

- How many emergency service vehicles (police patrol cars, fire companies, ambulances) should a city have?
- Where should the vehicles be located?
- Should the number of locations change with time of day or season?
- What should the area of responsibility be for each vehicle?

Tactical deployment problems deal not with tactics at the scene of an emergency, but with the daily operations of the service agency and the decisions that it faces in the short term. These include:

- How many service vehicles should be dispatched to a particular call?
- Which vehicles should be dispatched?
- Should a call wait in queue until the closest vehicle becomes available?
- When and how should available vehicles be relocated to improve coverage?

In this section we are primarily concerned with models for suggesting and evaluating alternative *strategic* deployment policies. Strategic problems are the most critical ones facing most communities, and these models have been tested most widely in a number of cities.

Deployment analysis requires a precise description of the problems to be solved and careful selection of the tools to be used for solving them. No two communities will have precisely the same deployment problems or precisely the same constraints on what constitutes a feasible solution. Thus, the analysis will usually proceed differently for each city. The steps in a deployment study are discussed in Sec. IV. In this section we describe the individual models developed at The New York City-Rand Institute and try to provide enough information for a potential user to determine whether he has a need for any of them, and if so, which ones.

The usefulness of a model depends on many things. For example, a model that must be run on a large computer would be useless to an agency not having access to a large computer. Also, if the data required by the model are very difficult to obtain, this will diminish its utility for some users. In some communities the cost of using the model would not justify the expected benefits. In others, the expertise required to use the model might not be available to the user.

In order to aid in the evaluation of the usefulness of a model, we provide detailed information on the following attributes:

- *Structure.* A brief description of the model and how it works.
- *Uses.* The deployment questions that the model is designed to address.
- *Data Requirements.* The data that must be obtained before the model can be used.
- *Output.* The results produced by the model.
- *Assumptions.* The most important assumptions that were made in developing the model and the restrictions that they impose on the results.
- *History of Use.* A summary of where the model has been used and with what results.
- *Resources Needed for Implementation.* The effort and cost involved in preparing the model for use in a city (exclusive of data collection), the size and type of computer that must be available, and special computer languages needed.
- *Computation Cost.* The approximate cost of making a single run with the model.
- *Documentation.* A list of publications that describe the model. There are generally four types of documentation available for each model; these may be published separately or combined in various ways as two or three volumes:

  (1) An *executive summary*, containing a nontechnical introduction to the model, information to assist an administrator in deciding whether to use the model, and details about how the computer program can be obtained.
  (2) A *technical description*, designed to provide an analyst with an understanding of the theoretical underpinnings of the model.
  (3) A *user's manual* describing step-by-step how the computer program is operated once it is installed on a computer system.
  (4) A *description* of the computer program. This document is designed for use by programmers and data processing personnel. It provides sufficient information to permit installation of the model, construction of the required data base, and modification of the model, if desired, to match the special requirements of the agency.

A. THE SQUARE-ROOT MODEL FOR ESTIMATING AVERAGE TRAVEL DISTANCES

Structure

One of the most important measures of the performance of an emergency service is the time that elapses between the call for service and the arrival of the responding unit or units at the scene (called the *response time*). One of the principal components of response time (and the only one that will generally be affected by a change in deployment policy) is *travel time* (the time between the start of the unit's trip and its arrival at the scene); and travel time is primarily a function of the distance that the unit must travel.

A very simple relationship, called the *square-root law*, has been found to give accurate estimates of the average travel *distances* for emergency service vehicles in

a region. It is based on the fact that, under some restrictive conditions, it can be proven mathematically that the average travel distance of the closest available unit of a given type (ladder company, engine company, ambulance, police car) to the scene of an incident in a region is proportional to the square root of the region's area and inversely proportional to the square root of the number of units of that type available in the region at the moment of dispatch. In particular, if A is the area of the region (in square miles) and N is the number of units available, then the average travel distance (in miles) of the closest available unit in a region to the scene of an incident is given by

$$D = c\sqrt{A/N}\ , \qquad \text{(A.1)}$$

where c is a constant that depends on the street configuration, the manner in which the units are distributed throughout the region, and whether or not the units operate from fixed locations. The same relationship holds for the distances to the second closest unit, third closest, etc. Only the value of the constant changes.

Since the number of available emergency vehicles will vary over time, relationship (A.1) cannot be used directly to estimate the average travel distance to calls for service over the course of an hour or several hours. However, it has been found that if the *average* number of available units in a region is not too small (over two units), a reasonable estimate of the average response distance to the closest available unit in a region is given by

$$D = k\sqrt{A/(M - b)}\ , \qquad \text{(A.2)}$$

where M is the number of units assigned to the region, b is the average number of units busy (i.e., not available to respond) in the region, and k is a constant of proportionality (generally slightly different from c).

Equation (A.2) is what we call the Square-Root Model. Of all the models described in this report, it is the simplest in form, has the fewest data requirements and can be transferred the fastest to another city.

For example, consider a region having an area of four square miles and ten units assigned. If, on the average, one unit is busy, and data show that the constant c for this region is 0.5, the average travel distance is approximately $D = 0.5\sqrt{4/(10-1)} = \frac{1}{2}\sqrt{4/9} = 1/3$ mile.

Uses

The Square-Root Model is used primarily as a component of other models (see, for example, Secs. C and F, below). However, it can easily be used by itself for the following purposes:

- To describe current average response distances of emergency vehicles in a city or to compare response distances in different regions of a city;
- To determine the effect on response distance of adding additional units or removing units;
- To determine the number of units required (by region and/or time of day) to achieve desired average response distances;
- To determine the effect of projected rates of calls for service on response distances, for long-range planning purposes.

It is an approximate, area-wide planning model useful for making rough estimates.

Data Requirements

The only data required as input to the model are:

(1) The area (A) of the region in square miles.
(2) The number (M) of service units of the given type in the region.
(3) Estimates of the hourly incident rate[1] (λ). (This can be determined for different times of day, seasons, or days of the week. It can also be a projection for a future year.)
(4) The expected total work time (S) in hours for all units of the given type at an average incident. (This can often be determined from a small sample of reports on incidents. For example, for engine companies, add together all the hours worked by all engines at all the incidents in the sample, and divide by the total number of incidents.)
(5) The constant k for the region. (We have found that the value of k for each emergency service shows little variation among regions of a city and, in fact, among the several cities in which we have worked. For example, for units in fixed locations, such as fire engines and ladders, the value of k has been found to be approximately 0.55 [approximately 0.94 for second-closest units]. For mobile units such as police cars, the value of k is approximately 0.83.)

[Note that b (the average number of units busy) is obtained by multiplying λ and S together (i.e., $b = \lambda S$).]

Output

This model is a versatile and useful tool in deployment analysis, and can be used both to *describe* a given allocation policy (determine the consequences of implementing the policy) and to *prescribe* a new one (find the number of companies needed to achieve a stated objective).

Descriptive. For a given incident rate and allocation of units in a region, the expected distance to the closest available unit is obtained from (A.2). In addition, the average number of busy units (b) is given by λS (while the average number of units available is, of course, $M - b$), and the average number of units busy per square mile (a useful index for comparing different regions) is given by b/A.

By repeated use of (A.2), it is possible to determine the effect of different incident rates on response distance, and to evaluate the consequences of locating more or fewer units in the region. In fact, in long-range planning research for the New York City Fire Department, graphs were drawn showing response distance as a function of M for various projected fire alarm rates for different times of day and different seasons.

Prescriptive. In deployment planning one might want to assign units to areas to achieve a desired level of average response distance (or time). This can be done by solving (A.2) for M in terms of D. That is

$$M = b + A\,[k/D]^2. \qquad \text{(A.3)}$$

[1] The *hourly incident rate* is the average number of calls for service received by the emergency service agency in one hour.

Of course, M will not usually be an integer. However, the resulting M can be rounded to an integral number of units.

[Note: If the relationship between response distance and travel time is known (see, for example, Sec. B below), it can be used to transform the response distances produced by this model into travel times.]

Assumptions

Relationship (A.1) was derived analytically assuming idealized conditions that would significantly restrict its usefulness and applicability. The derivation assumes an infinitely large region in which the units are located either uniformly on a grid or purely at random, calls for service are distributed homogeneously in space, and emergency vehicles travel along simple response paths. Despite the idealized assumptions, rigorous empirical and simulation tests[2] have shown that the relationship holds remarkably well under a wide range of realistic conditions. These conditions include wide variations in incident rates and in the number and placement of units.

It must be remembered, however, that this is an approximate, area-wide planning model. It does not consider specific unit locations, the location of individual incidents, or major barriers to travel. It is primarily useful for obtaining rough estimates and for making over-all comparisons among alternative deployment policies.

History of Use

Since its development in 1970, this model has been used extensively by The New York City-Rand Institute to obtain quick and inexpensive first approximations of the value of deployment changes. It has been used in studies of emergency service agencies throughout the country. In particular, in 1971 and 1972 it was the principal model used by the New York City Fire Department in making its decision to disband six fire companies and permanently change the locations of seven others. It was also used in a study performed by the Institute that analyzed the deployment of ambulances in Washington, D.C.

In 1973 the square-root model was used as part of a more flexible and sophisticated model for analyzing fire company deployment problems called the Parametric Allocation Model (Sec. C, below). In 1975 it was imbedded in the Patrol Car Allocation Model (Sec. F, below), which is used to analyze police deployment problems.

Resources Needed for Implementation

The data and computational requirements for the Square-Root Model are modest, and the calculations can be made with a desk calculator. The data can be collected in a few days (or estimated in a few hours). The single equation is easy to understand and explain. As a result, very little effort or cost is involved.

The model does not require the use of the computer; an electronic calculator that takes a square root (or any calculator plus a table of square roots) will suffice. However, for convenience and speed, especially when calculations are being made

[2] See below for descriptions of simulation models.

for a large number of regions or deployment alternatives, the model can be easily programmed for use on a computer.

Computation Cost

It costs practically nothing to calculate the average response distance in a region for one given set of conditions. Therefore, the model can be used many times to get an idea of how average response distance would vary under a wide range of conditions.

Documentation

The theoretical framework and mathematical derivation of the model is presented in:

> Peter Kolesar and Edward H. Blum, *Square Root Laws for Fire Company Travel Distances*, R-895-NYC, The New York City-Rand Institute, June 1975.

This report also describes how the model was validated for estimating fire company travel distances and illustrates several ways in which it can be applied to deployment analysis problems. It is designed to be read by persons familiar with mathematics and system analysis.

A short discussion of how the model was validated for estimating police patrol car response distances (as well as for estimating fire company travel distances) is contained in:

> Edward Ignall, Peter Kolesar, and Warren Walker, *Using Simulation to Develop and Validate Analytical Emergency Service Deployment Models*, The New York City-Rand Institute, P-5463, August 1975.

A description of how the Square-Root Model was used by the Fire Department of New York City when it made several important changes in the number of and location of its fire companies in November 1972 is contained in:

> E. J. Ignall, P. Kolesar, A. J. Swersey, W. E. Walker, E. H. Blum, G. Carter, and H. G. Bishop, *Improving the Deployment of New York City Fire Companies*, P-5280, The New York City-Rand Institute, July 1974.

B. THE TRAVEL TIME ANALYSIS PROGRAM

Structure

Travel time, defined as the length of time between the start of an emergency unit's trip and its arrival at the scene, is an important measure of the effectiveness of an emergency service. The time for any specific response may be a function of many variables in addition to the distance traveled. The time to travel a given distance can vary with the traffic conditions, time of day, etc. However, extensive stop watch and odometer investigations of fire company travel times in several cities have revealed that most of these factors had only a small effect or were relatively constant over all responses. So, a good estimate of the expected travel time for a

response can be obtained knowing only the travel distance and the constant effect of the other influences.

Analysis of data on over 2000 responses made by fire companies to actual alarms in New York City revealed two different functional forms for relating travel distance to expected travel time. For *short* responses during which units are unable to attain cruising speeds, travel times increase with the square root of the distance traveled. That is

$$T = c\sqrt{D}\,, \tag{B.1}$$

where T is the expected travel time in minutes, D is the travel distance in miles and c is a constant (not the same as that in the Square-Root Model, above).

For *long* responses, which allow responding units to reach cruising speeds, the travel time increases linearly with the travel distance. That is

$$T = a + bD, \tag{B.2}$$

where a and b are constants.

Combining functions (B.1) and (B.2) a piecewise square-root/linear travel time function is obtained that can be applied to any travel distance:

$$T = \begin{cases} c\sqrt{D}, & D \leq d \\ \\ a + bD, & D \geq d. \end{cases} \tag{B.3}$$

Here d is a "cutoff" distance where the two curves join, and the constants a, b, and c must be selected in such a way that the match between the curves is appropriate. The computer program described in this section, which has been given the name "Travel Time Analysis Program," uses statistical curve-fitting (regression) methods to determine appropriate values for the parameters a, b, c, and d using empirical data about responses of actual emergency service vehicles. The program also fits a fourth function:

$$T = \alpha D^{\beta}. \tag{B.4}$$

The parameters α and β are needed as input to the Parametric Allocation Model (Sec. C, below).

The Travel Time Analysis Program can be used by a city to analyze travel time data that it collects on responses made by its units. Analysis of data from travel time experiments in several cities other than New York have shown a surprising consistency in the values of the parameters obtained when (B.3) is fitted to the empirical data from each city, for each region of a city, and at all times of day. Use of these "average" parameters ($a = 0.65$, $b = 1.70$, $c = 2.10$, and $d = 0.38$ in Equation B.3) is generally sufficient for approximate deployment analysis. Equation (B.3) with these "average" parameters is depicted graphically in Fig. 1.

Use

Travel time is widely used as a measure of the effectiveness with which an emergency service agency (such as a fire department, police department, or ambu-

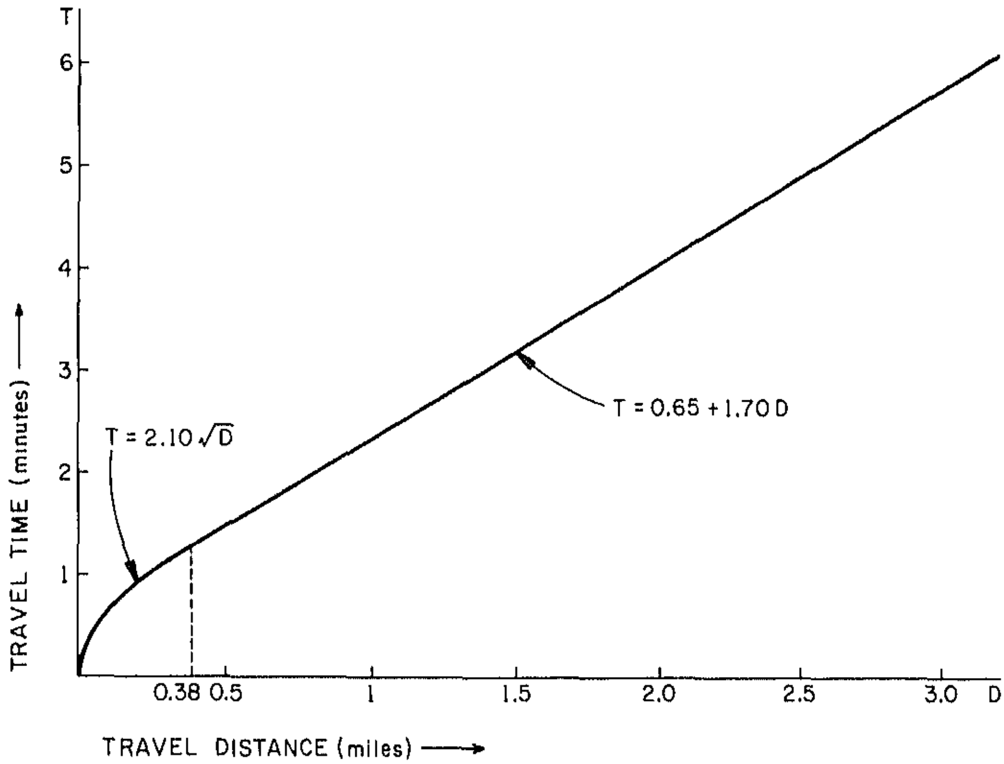

Fig. 1—The relationship between travel time and travel distance ("average" parameters)

lance service) serves a region. Travel *distance* is an important measure (the Insurance Services Office uses it to evaluate the fire service in a city), but travel *time* is more directly related to the objectives of emergency services. Using the Travel Time Analysis Program, a function can be determined for translating travel distances into good estimates of travel times. In the case of ambulances, the same method can be used to calculate the travel time from the scene of an incident to the destination hospital.

Data Requirements

Determination of the best relationship between travel distance and travel time for a particular city or region of a city requires certain items of data that are not generally collected. These include, for each response, the travel distance, travel time, location of the incident, and time of day. In most cases, therefore, an experiment must be performed to gather these data.

In the experiment run in Wilmington, Delaware, for example, five fire companies were given stop watches and a coding form (the coding form is shown in Fig. 2). For each response, the starting odometer reading, ending odometer reading, and stop watch time were recorded, as well as the incident's location, its time of day, and the traffic and weather information. Data were collected on about 100 responses for each unit.

COMPANY: ____________

Codes:

Weather Condition	D=Dry W=Wet	
Traffic Condition	L=Light M=Moderate H=Heavy	
Usual Route Followed	U=Usual D=Detour	
Due	1E=First Engine 2L=Second Ladder	

Odometer before Responding	Odometer before Returning	Duration of Run Min. Sec.	Alarm Box Number	Time Out Hr.	Time Out Min.	AM PM	Weather Condition	Traffic Condition	Due	Usual Route Followed
123.4	125.2	03 12	0221	06	51	AM	W	L	1E	U
359.0	360.7	01 03	0172	12	13	PM	D	M	2L	D
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.	.					M				
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Fig. 2—Data form for travel-time experiment

Output

The data on responses are keypunched and fed into a computer program that produces summaries and analyses of the data. The program then finds the constants a, b, c, d, α, and β that provide the best fits to the data for relationships (B.1), (B.2), (B.3), and (B.4). [The program constrains the two parts of the function (B.3) to intersect and be tangent at a travel distance of d miles.] Included in the program's output are statistical analyses of the data, graphic summaries and statistical quantities that indicate how well the models fit the data. The effects of time of day, weather, and traffic conditions on travel velocity can also be examined with the program.

Assumptions

The Travel Time Analysis Program is primarily descriptive. It provides insight into the travel time characteristics of emergency service vehicles in a region. It is implicitly assumed that travel times can be reasonably well estimated from travel distances using one of the four functions listed above [(B.1) – (B.4).] Other relationships were tried on New York City's data, but one of the four specified functions always provided the best fit for each company and for all times of day. Physical considerations related to cruising speeds also suggest that travel time should be linearly related to travel distance for long travel distances and proportional to the square root of travel distance for short distances.

History of Use

This model was first used to analyze data collected in a stopwatch experiment conducted in New York City during the summer of 1971. Since that time it has been used to analyze data collected by emergency service vehicles in similar experiments in Yonkers, New York, Wilmington, Delaware, Jersey City, New Jersey, Washington, D.C., Trenton, New Jersey, Dade County, Florida, and San Jose, California.

Resources Needed for Implementation

It is simple to collect and keypunch the information needed for this model. Emergency service agencies have conducted the experiments completely on their own in each of the cities named above.

The Travel Time Analysis Program is written in Fortran IV and requires approximately 150K bytes of core storage when run in the batch mode on an IBM System 360 or 370 computer.

Computation Cost

It costs very little to use the Travel Time Analysis Program. Our experience is that it costs approximately $1.00 to process information on 300 responses.

Documentation

Two reports explain the Travel Time Analysis Program and its use:

Peter Kolesar and Warren Walker, *Measuring the Travel Characteristics of New York City's Fire Companies*, The New York City-Rand Institute, R-1449-NYC, April 1974.

This report documents the results of a stopwatch experiment conducted in New York during the summer of 1971. Information on over 2000 responses was collected from 15 participating fire companies. The results showed that response patterns are remarkably similar in most parts of New York City and that there is little significant time-of-day effect. Each of the case study reports described in Sec. III below includes the results of the travel time experiment carried out in that city.

Jack Hausner, *Determining the Travel Characteristics of Emergency Service Vehicles*, The New York City-Rand Institute, R-1687-HUD, April 1975.

This report describes how to carry out a travel time experiment (including instructions and a sample coding form) and fully documents the Travel Time Analysis Program. The last half of the report serves as a user's manual for the program, including the program listing, sample printouts, and a detailed explanation of the output.

C. THE PARAMETRIC ALLOCATION MODEL

Structure

The problem of how to allocate a given number of fire companies[3] to different regions of a city is one of the fundamental deployment questions that must be answered by fire department management. Companies can be allocated according to many different performance objectives. Each objective generally implies a different allocation. Two possible performance objectives are: (1) provide the same average travel time in each region; (2) minimize the average travel time to all fires in the city.

The Parametric Allocation Model is designed to allow the decisionmaker to examine the allocations that result from assigning different weights to these objectives. This is accomplished by assigning different values to an input called a *tradeoff parameter*. The interactive computer program that implements the model first reads a previously created file containing data on various types of fire alarms in each region of the city. The user then provides two input quantities: the total number of companies to be allocated and the value of the tradeoff parameter. The program begins its calculations by assigning the minimum number of companies required to respond to and work at the average number of incidents that occur in each region. It then allocates the remaining companies according to the specified value of the tradeoff parameter, which indicates the balance among the performance objectives desired by the user. Once the allocation is determined, the program calculates and prints out values of various performance measures that it predicts will result if the allocation is implemented. The model can also be used to predict the values of performance measures that would result from implementation of any specific alloca-

[3] A *fire company* is any fire department vehicle and its complement of firemen. The two most common types of fire companies are engine (or pumper) companies and ladder (or truck) companies.

tion supplied by the user. The general procedure for using the model is shown in Fig. 3.

Uses

Even though a city's firehouse locations probably once made sense, they should be reevaluated periodically. As a city changes over the years, its fire experience also changes. Formerly well-maintained neighborhoods may become run-down and suffer increasing fire hazards, or vacant land may be built up and create a need for fire protection where none existed before. On the other hand, urban renewal may turn a problem area into one of low risk. A decision must also be made about where to locate a new firehouse whenever an outmoded firehouse is scheduled to be closed.

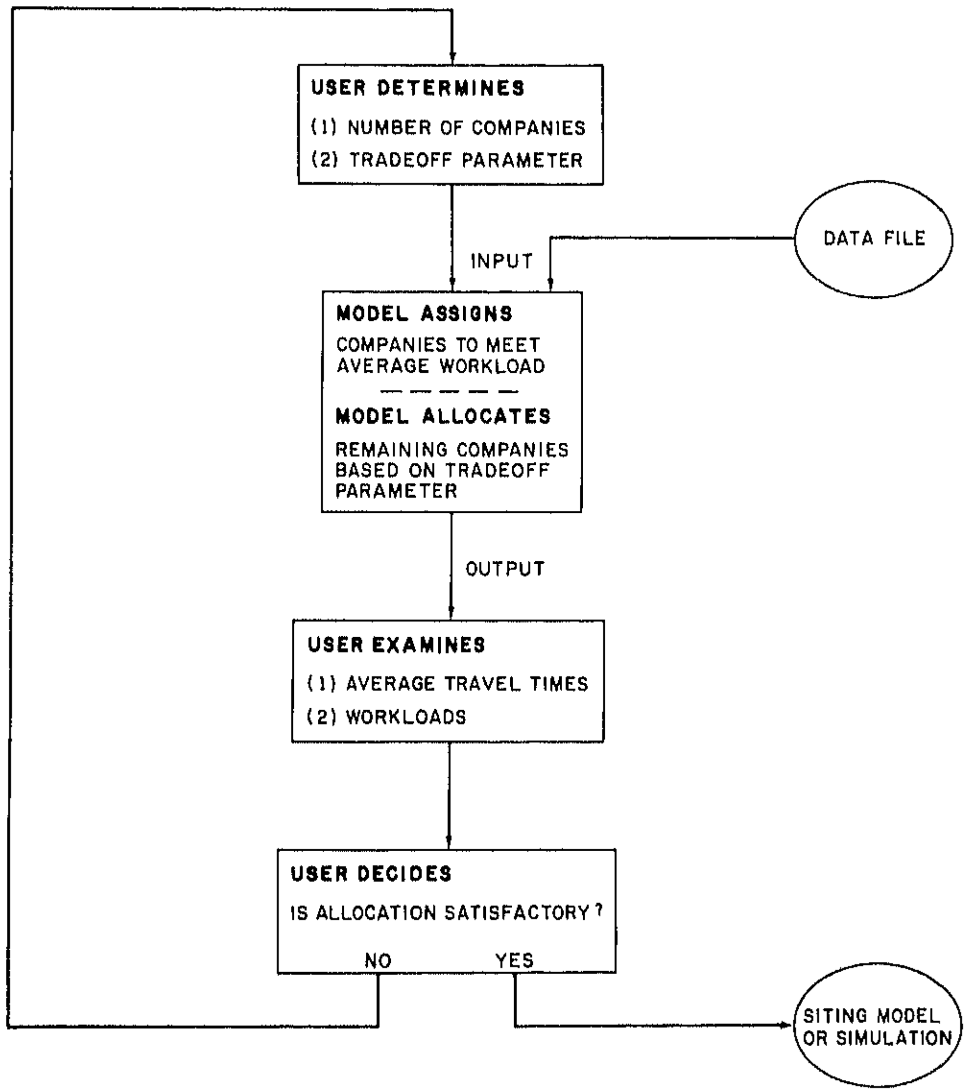

Fig. 3—Steps in the use of the Parametric Allocation Model

Should the new house be at the same location as the old one? Should it be put into an area of increasing fire risk? Or should it be put into a low-density area that currently has a low level of fire protection? Similar questions arise if a company is to be eliminated or if a company is to be added to the department.

The Parametric Allocation Model provides the user with a general picture of the number of fire companies to be assigned to different regions of a city. It is simple and inexpensive to use and requires very few data. But it cannot be used to evaluate specific locations for the companies in detail. Its primary purpose is to assist in the *initial* steps of a firehouse location study.

The Parametric Allocation Model can be used to compare average travel times and workloads among regions of the city to show whether or not the current distribution of fire companies is satisfactory. If sizable imbalances are found, the model can also be used to determine how to reallocate the existing units among the regions to provide more balanced fire protection. If proposals for additional fire companies or for fewer fire companies are being considered, the model can also be used to determine the regions that should gain or lose companies.

Once a fire department has chosen the number of companies to be assigned to each region of the city, alternative configurations of station sites within each region can be evaluated in detail using the Firehouse Site Evaluation Model (Sec. D, below) or the Fire Operations Simulation Model (Sec. E, below). Both require substantially more data than the Parametric Allocation Model.

The Parametric Allocation Model can also be used to analyze allocation problems related to other emergency services (for example, it has been used to analyze the deployment of emergency medical service rescue vehicles in Dade County, Florida). But the Patrol Car Allocation Model (Sec. F, below) is more appropriate when queueing of calls for service is common (for example, in police patrol operations).

Data Requirements

To use the Parametric Allocation Model, the city to be studied must be divided into *demand* regions. Each demand region should contain at least two fire companies of the same type. It should have a reasonably compact shape and should be relatively homogeneous with respect to fire hazards to life and property, and with respect to other potential fire-fighting problems, and alarm rates. For each demand region the user must supply:

- The area (in square miles)
- The alarm rates for different types of alarms (structural fires, false alarms, etc.)
- The number of engines and ladders currently in the region
- An indication of the relative hazards in the region

In addition, the model requires the following information:

- An estimate of the relationship between travel time (T) and travel distance (D) of the form $T = \alpha D^{\beta}$ (see Sec. B above).[4]
- A specification of the dispatch policy being used; either "send 1" (commonly

[4] This function is used in the Parametric Allocation Model instead of (B.3) in order to facilitate the mathematics. It has been found to produce travel time estimates that are good enough for analyzing alternative deployment policies.

used in dispatching fire engines), or "send 2 if the two closest units are both available, but send at least 1" (the dispatch policy used in New York City).

- The way in which the deployment objectives are to be weighted, which is specified in terms of the value of a tradeoff parameter (call it P).

  P = 0 will equalize average travel times in all regions;
  P = 1 will minimize the average travel time to all incidents;
  P large will equalize the workload of all units;
  P between 0 and 1 produces some compromise between equal and minimum average travel times. A value of P = ¼ has been found to produce approximations close to the actual fire company allocations in several cities.

Output

The model can be used in a descriptive or prescriptive mode. In the prescriptive mode it gives the number of vehicles to be assigned to each region to produce the desired deployment objective. In addition, to facilitate a comparison of this allocation with any other allocation, it gives, for each region and for the regions combined, the resulting average travel times for the first- and second-arriving units, the average travel distance for the first-arriving unit, the average number of units busy, and the average number of units busy per square mile.

In the descriptive mode, the number of units is input for each region and the program calculates the same performance measures listed above.

Assumptions

The Parametric Allocation Model makes the same assumptions as the Square-Root Model (Sec. A, above). In fact the Square-Root Model is used to estimate average travel distances in each of the regions. In addition, the model assumes that $T = \alpha D^{\beta}$ is a reasonable function to use to translate average travel distances into average travel times in all regions being considered (see Sec. B, above).

If the user wishes to aggregate small regions (to which fractional allocations have been made) into larger regions, he must make sure that each of the regions has a similar density of incidents and a similar distribution of incident types. If this is not so, the travel times in the aggregated region will be slightly lower than those predicted by the model. The regions being aggregated should also have similar fire-fighting hazards.

History of Use

The Parametric Allocation Model was developed during 1972 and 1973 to assist the New York City Fire Department in generating and evaluating alternative regional allocations of its engine and ladder companies. In December 1974 and June 1975 it was used by the Department to determine the regions that should lose fire companies when the City required the Fire Department to make substantial cuts in its budget.

It was also found useful in analyzing: fire company deployment in Yonkers, New York, Wilmington, Delaware, Tacoma, Washington, and Jersey City, New Jersey; deployment of ambulances in Washington, D.C.; and deployment of emergency medical service rescue vehicles in Dade County, Florida.

The Principal Investigator in the Dade County project has written: "The model is an excellent tool in assisting management of emergency services. Among its strong points are the wide range of policy options it presents to the decision maker, the relative ease of implementation and the low cost of associated computer usage."

Resources Needed for Implementation

This model is almost as easy as the Square-Root Model to prepare for use in a city. It requires almost the same data, and is only slightly harder to explain. The project team in Dade County, Florida, with only the user's manual for the model and a few telephone conversations with Institute staff, reprogrammed the model for their computer, created the required data base for emergency medical service rescue vehicles in Dade County, and used the model to develop a set of deployment recommendations.

The best documented and most widely used version of the Parametric Allocation Model is written in an interactive computing language called BASIC.[5] A batch version of the program has been written in PL/I. On a PDP-10 computer, the interactive version of the allocation model requires 4000 words of core (approximately equivalent to 16K bytes of storage on an IBM System 360 or 370 computer).

The time and effort required to create the input data file needed by the allocation model for use in a particular city will depend on whether or not: (a) computerized files of incident reports have been maintained and (b) the city has already been divided into regions of similar fire-fighting demands. If these conditions are met, then in less than a week a management analyst can prepare the data file. A few days of assistance from data processing personnel may be required. Otherwise, an additional two man-months will probably be required to collect and process the data.

Persons with the skills to prepare the data, run the model, and analyze its output are likely to be found in most municipal governments. Little or no outside technical assistance should be required.

Computation Cost

The Parametric Allocation Model is very inexpensive to use. A single run costs approximately twenty cents, although the cost of a run will vary from installation to installation depending upon the price structure.

Documentation

Three reports are available that document the Parametric Allocation Model: a nontechnical introduction, a user's manual for the on-line program (which includes a program listing), and a technical description. They are:

[5] This version is available for use through Compu-Serv Network, Inc., a national computer time-sharing service. An agency wishing to use the model in this way need only have access to a computer terminal that can be coupled to the computer by telephone.

Kenneth Rider, *A Parametric Model for the Allocation of Fire Companies: Executive Summary*, The New York City-Rand Institute, R-1646/1-HUD, August 1975.

Kenneth Rider, *A Parametric Model for the Allocation of Fire Companies: User's Manual*, The New York City-Rand Institute, R-1646/2-HUD, August 1975.

Kenneth Rider, *A Parametric Model for the Allocation of Fire Companies*, The New York City-Rand Institute, R-1615-NYC/HUD, April 1975.

The use of the Parametric Allocation Model in performing fire company deployment analyses is described in several of the case study reports that are discussed in Sec. III. The best illustration of its use is provided in:

Kenneth Rider, Jack Hausner, et al., *An Analysis of the Deployment of Fire-Fighting Resources in Jersey City, New Jersey*, The New York City-Rand Institute, R-1566/4-HUD, August 1975.

D. THE FIREHOUSE SITE EVALUATION MODEL

Structure

Once a fire department has chosen (at least tentatively) the number of companies to be assigned to each region of the city, it is not difficult to develop several alternative arrangements of fire companies that might lead to desired levels of performance. In some small communities it will not be difficult to choose the best alternatives by studying maps on which the various alternatives are displayed. However, in larger cities it is nearly impossible for a planner to look at a map and make accurate "guesses" regarding the workloads of the units or areas where travel times will be too high. The Firehouse Site Evaluation Model (the "siting model") was developed to help planners evaluate alternative arrangements of fire companies. It is a descriptive model that estimates a large number of performance measures for a given proposed arrangement of fire companies.

Using grid locations assigned by the user to alarm boxes and firehouses, the model estimates the distances traveled by companies to each alarm box. The distances are used to divide the city into response areas, where a company's *first-due response area* is the region of the city to which it is closer than any other company; its *second-due response area* is the region in which it is second closest; and so on. After calculating the response distances, the program estimates travel times by using a simple mathematical formula to relate fire vehicle travel time and travel distance (see Sec. B). It then aggregates travel times by region, response area, etc., and prints summary statistics on travel times (and estimated workloads) for each group of boxes.

Uses

The model has been designed primarily to assist in the evaluation of the adequacy of present fire company locations, and the examination of the consequences of implementing alternative arrangements of companies, using travel times and com-

pany workloads as performance measures. The siting model can be applied equally well to evaluating ambulance locations if the ambulances are usually available to respond from fixed locations.

Data Requirements

Most of the data required by the siting model are related to either discrete incident locations (which the model refers to as "alarm boxes") or the current arrangement of fire companies.

The data on the current arrangement of *fire companies* include:

- The location of each firehouse, given by its (x,y) coordinates on a grid map of the city;
- An ordered list of the closest fire companies to each alarm box (if this information is not easily available the program can generate it using the grid locations of the fire companies and alarm boxes).

The data for each *alarm box* include:

- Its location, given by its (x,y) coordinates on the same grid used for identifying firehouse locations;
- The number of alarms that occurred at that box in the past year (or that are projected to occur);
- The number of structural alarms that occurred at that box;
- An indication of whether the box is considered a "target hazard" (more important than others for achieving rapid response);
- The demand region to which the box belongs (explained in Sec. C above).

In addition, the relationship between travel distance and travel time must be specified in terms of one of the functions described in Sec. B.

Output

Since one arrangement of firehouses will rarely result in travel times that are superior to those of another arrangement for every alarm box, the siting model provides information on travel times to groups of alarm boxes. The boxes are grouped in several ways:

- Citywide (aggregate results are printed for the city as a whole);
- By demand region (results are printed separately for each of the previously defined demand regions constituting the city);
- By company response area (the boxes responded to by each company are aggregated, and summary statistics are printed);
- For the "affected region" (in any use of the model, results are presented for two configurations of companies: a previously defined configuration that is called "current," and the new one under consideration, called "proposed;" the "affected region" is the set of boxes for which travel times in the current configuration differ from the travel times in the proposed configuration);
- All boxes that represent special hazards (travel times are printed for each of these special "target" hazards and summarized for the whole group).

For each of the above groups of alarm boxes (except company response areas) the siting model provides the values of the following performance measures for both the "current" and "proposed" configurations:

- Average travel time to an alarm box (giving equal weight to each box);
- Average travel distance to an alarm box;
- Average travel time to a serious fire (taking into account that some alarm boxes have more serious fires than others);
- Average travel distance to a serious fire;
- Maximum travel time to any box in the group.

All of these statistics are calculated separately for engine companies and ladder companies, and can be obtained for first-due, second-due, third-due, etc. responses, up to the response level requested by the user.

The output for each demand region, and the citywide output as well, includes a report that shows the number of alarm boxes whose travel time under the proposed configuration falls into each of a number of half-minute intervals. (This kind of information can be used to construct a graph of the type called a *histogram.*) This can be used to see how frequently very long travel times occur using a particular configuration of companies and to consider other questions that could not be answered if only *average* travel times are provided.

For each company's response area (both current and proposed), the program prints the number of boxes in the area, the average and maximum travel times, and the alarm rates in the area. The alarm rates provide an estimate of the workload of the fire companies (based on historical alarm rates in the response area). These can be used to determine whether a proposed configuration of firehouses will result in an undue strain on a particular fire-fighting unit or large workload imbalances among the units.

Assumptions

The siting model assumes that units are always available in their firehouses to respond to an incoming alarm. (This is a reasonable assumption for most cities. The travel time estimates produced by these models will be useful for making deployment decisions as long as an average fire company is available at least 90 percent of the time.) It also assumes that the closest units are always dispatched to an alarm. (For a model that can be used to evaluate alternative arrangements of companies but that relaxes these two assumptions see Sec. G, below).

Travel distance estimates are obtained by using the grid coordinates to calculate either the right-angle distance between the two points or the Euclidean (straight line) distance, which is then multiplied by a factor (1.15 unless the user supplies a different factor). Travel times are estimated from the travel distances by using one of the functions described in Sec. B with parameters supplied by the user. These travel distance and travel time estimates are used in the model because they are fast to process by computer and require the user to gather very few data. They are approximations that will produce slightly incorrect representations of the travel distance and time for an individual trip, but have been shown to be sufficiently accurate for policy comparisons.

History of Use

The Firehouse Site Evaluation Model was programmed, tested, and refined during 1973 and 1974 by members of the staff of The New York City-Rand Institute. It was the primary tool used in the analysis of fire company deployment policies in Yonkers, New York, Jersey City, New Jersey, Wilmington, Delaware, and Trenton, New Jersey.

Each of these cities is in the process of making substantial changes in the number and arrangement of its fire-fighting resources based on the results of the analysis. For example, in Trenton it was used to show the city administration how it could obtain approximately the same level of fire protection with 22 percent fewer engine companies. In Wilmington, one fire company was eliminated and a long-range plan was developed for changing the locations of eight others by building six new firehouses. Yonkers has already purchased sites for two new firehouses, whose locations were determined on the basis of runs made with the siting model.

Resources Needed for Implementation

The siting model is easy to understand and to use. It has been successfully transferred to: a team of uniformed personnel in the Jersey City Fire Department (who, with no outside assistance, used it to analyze the deployment of ambulances); a management analyst in the Trenton Business Administrator's Office (who used it to develop several arrangements of fire companies that were more politically acceptable than those recommended in the Trenton case study report); and a fiscal analyst in the Wilmington Mayor's office (who plans to use it to update the recommendations in the Wilmington case study report as conditions change in the future).

The siting model is written in Fortran and can be run as a batch program or in an interactive mode. It is also available for use through Compu-Serv Network, Inc., a national time-sharing service. On a PDP-10 computer, the siting model requires 27,000 words of core storage for a city with 750 alarm boxes and 30 fire companies (approximately equivalent to 108K bytes of core storage on an IBM System 360 or 370 computer).

The time and effort required to set up the siting model for use in a particular city will depend on whether or not: (a) grid locations have been determined for alarm boxes and firehouse locations, (b) computerized files of incident reports have been maintained, and (c) the city has already been divided into regions of similar fire-fighting demands. If these conditions are met, then a management analyst can set up the model in two or three man-weeks. Otherwise, an additional two man-months will probably be required to collect and process the data. Persons with the skills to set up and run the siting model and analyze its output are likely to be found in most municipal governments. Little or no outside technical assistance should be required.

Computation Cost

The cost of computer time to run the siting model depends primarily on two factors: the number of changes to be made in the existing configuration of fire companies and the number of alarm boxes in the city.

For a city with 750 alarm boxes and 30 fire companies, a single run using the model costs approximately $5.00 using the time-sharing service, although the cost

of a run will vary from installation to installation depending upon the price structure.

Documentation

Two reports have been published that document the Firehouse Site Evaluation Model: a nontechnical introduction and a user's manual (which includes a program listing). They are:

Warren E. Walker, *Firehouse Site Evaluation Model: Executive Summary*, The New York City-Rand Institute, R-1618/1-HUD, June 1975.

Peter Dormont, Jack Hausner, and Warren Walker, *Firehouse Site Evaluation Model: Description and User's Manual*, The New York City-Rand Institute, R-1618/2-HUD, June 1975.

The use of the Firehouse Site Evaluation Model in performing fire company deployment analyses is described in several of the case study reports that are discussed in Sec. III. The best illustration of its use is provided in:

Jack Hausner and Warren Walker, *An Analysis of the Deployment of Fire-Fighting Resources in Trenton, New Jersey*, The New York City-Rand Institute, R-1566/1-TRNTN, February 1975.

E. A SIMULATION MODEL OF FIRE DEPARTMENT OPERATIONS

Structure

The Simulation Model of Fire Department Operations is a computer program that imitates step-by-step what happens in the real operations of a fire department. The program tracks each of a large number of incidents from the time the fire begins, through the time it is reported to the department by telephone or alarm box, and on through dispatch of companies, their arrival at the scene, their work at the incident and release, and finally their return to quarters and availability for another dispatch. The simulation acts like an "all-knowing" dispatcher who keeps in mind the location and status of all the companies and incidents, but does not pay attention to fire-fighting tactics or activities at the fire scene.

The simulation is the most detailed and sophisticated of the deployment models and therefore requires the largest data base. This level of detail and sophistication is, in general, needed only in the largest cities where alarm rates are very high and an average company is busy more than 10 percent of the time.

Uses

The simulation is a descriptive model; that is, given a deployment policy and a sequence of alarms, it describes the likely performance of the fire department. But it does not produce optimal policies or even recommend policies to be tested. It was designed principally for evaluating and comparing fire department deployment policies that differ with respect to:

- The number and location of fire companies;
- The number and identity of fire companies dispatched to alarms;
- The timing and specification of fire company relocations or move-ups that are made to cover an area whose coverage has been depleted by fires in the area.

However, considerable use has also been made of the simulation to develop and validate simpler deployment models, such as the Square-Root Model. After it is shown that the simpler model provides an adequate approximation, it can be used more economically than the simulation for future analyses.

Data Requirements

There are two sets of data needed to run the simulation. One data set contains a stream of alarms that has been generated outside the program—either from historical alarm data or by using an incident generator that is part of the simulation package. The information required for each alarm is: its location, how it was reported, the number of fire-fighting units of each kind required, and the length of time each unit should spend at the scene. If the incident generator is used, the following data must be supplied to the program:

- (x,y) coordinates for all potential incident locations (e.g., alarm box locations);
- The conditional probability of an alarm at each incident location (given an alarm occurs somewhere in the simulated area);
- The probability distribution of incident types at incident locations;
- Work times for every piece of fire-fighting equipment needed at each type of incident;

The other data set requires a symbolic description of the city and particular fire department being simulated. In particular, among the required data are:

- (x,y) coordinates for all firehouses;
- Alarm assignment cards (or "running cards") for each incident location showing the companies that respond to that location, by equipment type, in the order that they would be dispatched;
- A function for translating travel distances into travel times (see Sec. B above).

The simulation also requires a specification of the rules to be used to decide on the initial dispatch and on relocation. These rules may require that sections of the simulation be reprogrammed to reflect specific policies unique to the city.

Output

To facilitate the analysis, comparison, and evaluation of deployment policies, the simulation computes a large number of performance measures, including:

- A list of average response times (time from alarm receipt until the arrival of a fire company at the scene of the incident) for each type of unit for different categories of alarms (e.g., for two-alarm fires, the average re-

sponse time of the first-arriving ladder, third-arriving engine, last-arriving unit, etc);
- Activity measures for each fire-fighting unit (number of responses, number of incidents at which the unit worked, total work time);
- Company availability measures for different regions;
- Information for constructing a histogram of response times for each arriving unit (first engine, second ladder, etc.) for different categories of alarms. (See Sec. D for the definition of a histogram.)

In addition, fire company availability and response time information over the course of the simulation can be output to a tape or disk file for use in further analysis.

Assumptions

Fewer assumptions are made by the simulation model than by any other deployment model. The primary assumptions made are:

- The distance between any two points is a function of the right-angle distance, the Euclidean distance, and the direction of the streets in the region of the two points (this can be easily changed to suit the city);
- The seriousness of an incident (in terms of the length of time companies are required to fight it) is unaffected by how long it takes to get the required number of companies to the scene.

History of Use

The simulation model was programmed, tested, and refined during 1968 and 1969 by members of the staff of The New York City-Rand Institute with the help of personnel from the New York City Fire Department. Since then it has been applied to the analysis of a large number of deployment policies in New York and in Denver, Colorado.

Its use in New York City led to the implementation of several new deployment policies, such as the use of part-time "Tactical Control Units" and an "adaptive reponse" dispatching policy (which sends more units to potentially more serious alarms and fewer units to alarms that are not expected to be serious).

In Denver, the simulation was used after other methods of analysis had suggested that a reduction from 44 to 39 fire companies, together with the construction of six new firehouses, could provide almost the same level of fire protection as the current configuration. However, these conclusions had been based on a model which, like the Firehouse Site Evaluation Model, assumes that every fire company would always be available for dispatch from its station. The simulation model was run to see whether the real performance of the new configuration would be as good as anticipated, taking into account the unavailability of companies.

Chris Tomasides, Denver's Deputy Finance Director, reported that "one of our main concerns was what effect the changed configuration of fire companies would have on response times if the number of fire alarms continued to increase. The Rand simulation told us that even at double our present peak alarm rate there would be no significant deterioration in service. This was important in presenting our recommendations to the mayor and the City Council."

Resources Needed for Implementation

This is the most difficult of the deployment models to implement in a city. Using the simulation requires statistical expertise for preparation of the input data and interpretation of the output, and programming skills (someone who knows SIMSCRIPT I.5) for making the necessary changes to the simulation. Most fire departments do not possess staffs with these skills and will require the assistance of trained analysts from outside the department. In New York, personnel from The New York City-Rand Institute aided the Fire Department in using the simulation. In Denver, the research team was composed of faculty members from the University of Colorado, analysts from the Budget and Management Office of the City and County of Denver, members of the Denver Urban Observatory, and personnel from the Denver Fire Department.

The simulation requires at least a moderately large computer system (minimum requirements are 228K bytes of core storage and two auxiliary storage devices such as tape or disk). It requires a SIMSCRIPT I.5 compiler, a software package that is commonly available at university or commercial computation centers, but is unlikely to have been acquired by a city's data processing unit. If the compiler is not one furnished by Consolidated Analysis Centers, Inc., then additional programming changes may be required.

A fire department considering use of the simulation should plan on allowing at least one year between receiving the program and final analysis of policies. About two man-years of effort by analysts and department staff personnel together are required to prepare and use the model properly.

Computation Cost

Using an IBM Model 360/65, approximately ten alarms can be processed in one second of computer time. At The Rand Corporation, the typical computer charge for a run simulating about 4000 alarms is approximately $100. The cost of a typical simulation run may vary greatly from installation to installation, depending on the price structure, so this cost can only be considered a very rough estimate. In addition, one should note that the major portion of the cost of using the simulation is likely to be in the preparation of the input data, rather than in computer charges for running the simulation model. In Denver, approximately four man-months were required to adapt the simulation program and produce the input required by it, after geographical coding of incidents had already been completed.

Documentation

Two reports have been published that document the simulation model: a nontechnical introduction and a user's manual (which includes a complete listing of the program, its input data requirements and output reports). They are:

Grace Carter, Jan Chaiken, and Edward Ignall, *Simulation Model of Fire Department Operations: Executive Summary*, The New York City-Rand Institute, R-1188/1-HUD, December 1974.

Grace Carter, *Simulation Model of Fire Department Operations: Program Description*, The New York City-Rand Institute, R-1188/2-HUD, December 1974.

The following two documents discuss the application of the simulation to deployment problems of the New York City Fire Department:

Grace Carter and Edward Ignall, *A Simulation Model of Fire Department Operations: Design and Preliminary Results*, The New York City-Rand Institute, R-632-NYC, December 1970.

Grace Carter, Edward Ignall, and Warren Walker, *A Simulation Model of the New York City Fire Department: Its Use in Deployment Analysis*, The New York City-Rand Institute, P-5110-1, July 1975.

The use of the simulation in developing and validating simple analytic models for analyzing fire company deployment policies is described in:

Edward Ignall, Peter Kolesar, and Warren Walker, *Using Simulation to Develop and Validate Analytical Emergency Service Deployment Models*, The New York City-Rand Institute, P-5463, August 1975.

F. THE PATROL CAR ALLOCATION MODEL

Structure

The Patrol Car Allocation Model is a computer program designed to help a police department determine the number of patrol cars[6] to have on duty in each of its geographic commands[7] at different times of the day, on different days of the week, and in different seasons. It calculates a variety of performance measures for any allocation of patrol resources. Many of the measures are obtained from a multiserver priority queueing model (e.g., the fraction of calls that will have to wait in queue before being dispatched, the average length of time such calls will have to wait in queue, and the utilization of an average patrol car). Other measures are obtained using other models (e.g., average travel times are obtained using the Square-Root Model).

Uses

The Patrol Car Allocation Model has both descriptive and prescriptive capabilities. The descriptive capabilities permit displaying quantitative information about any given allocation of patrol cars by time of day and geographic command. This information may refer to the current allocation or any proposed allocation created by the user. This information permits the user to compare allocations and determine which one he thinks is best.

In the prescriptive mode, the Patrol Car Allocation Model has several capabilities. One of them will tell the user the *minimum number* of patrol cars that must be on duty in each geographic command during every hour of the day to meet certain standards of performance. Examples: What is the smallest number of patrol cars needed to assure that no more than 20 percent of the calls must be placed in queue? What is the smallest number of patrol cars needed to assure that the average total

[6] A *patrol car* is a police vehicle that responds to calls for service from the public. It is also called a "squad car," "radio car," "RMP unit," or "cruiser."

[7] A *geographic command* is an administrative unit also called a "precinct," "district," "division," or "area."

response time is less than 10 minutes? What is the smallest number needed so that both of these conditions are met?

A second prescriptive capability of the model will tell the user the "best" allocation of his existing resources among geographic commands and/or among different times of the day or week. The model permits the department to choose among several definitions of "best":

- The average percentage of calls that must be placed in queue is as small as possible, given existing resources;
- The average length of time calls of a given priority must wait in queue is as small as possible;
- The average total response time is as small as possible.

The third prescriptive capability of the model is a combination of the two already described. It permits the user to obtain an allocation of a fixed number of car-hours that (a) meets specified performance standards and (b) is the "best" allocation that can be achieved while meeting those standards.

Data Requirements

The user must provide the following information for each geographic command:

- Call rates and service times by hour of the day and day of the week (calls for service may be broken down into three priority levels);
- Area of the command (square miles);
- Street miles in the command;
- Response speed and patrol speed of patrol units;
- Crime rates;
- Parameters permitting a determination of the average amount of time during a tour that units spend occupied on activities other than calls for service (cfs) that make them unavailable for dispatch (e.g., time spent on meals, vehicle repairs, execution of warrants, etc.). This type of work is referred to as "non-cfs" work.

Output

For a given allocation of patrol units to geographical commands the program will estimate all of the following performance measures:

- Average number of units available (i.e., not busy on cfs work or non-cfs work);
- The amount of preventive patrol engaged in by the patrol cars;
- Average length of time from the dispatch of a patrol car until its arrival at the scene of an incident *(travel time)*;
- •• The percentage of calls that will have to wait in queue until a patrol car is available to dispatch to the incident;
- •• The average length of time (minutes) that calls of various priority levels will have to wait in queue;
- •• The average *total response time* (time in queue plus travel time).

The model will display all of these performance measures for any allocatioı proposed by the user. In addition, it will determine the minimum number of cars needed to meet standards of performance for any of these measures. The user may also choose any of the performance measures displayed with a double bullet (••), and the model will allocate a specified total number of car-hours so as to minimize the chosen measure. This capability permits allocation across time or geography or both. Therefore, the user can specify the total number of cars on duty in the city at a particular time of day, and the program will allocate them among geographic commands. Or the user can specify the total number of car-hours that can be fielded in a week (in one command, several commands, or all commands together), and the program will allocate patrol cars to tours so as to add up to the total number of car-hours.

Assumptions

The Patrol Car Allocation Model assumes that calls will be assigned to a single car assigned to the geographic command in which the call occurred, if one is available. If a call arrives when all cars in the command are busy, the model assumes that the call will be placed in queue until one of the cars in the command is available for dispatch. If several calls are already in queue when another call arrives, the model assumes that the order in which the waiting calls will be assigned to cars depends on their relative priority or importance. The model allows three priority levels. All priority 1 calls in queue will be dispatched before any call of priority 2, and all priority 2 calls will be dispatched before priority 3. The Patrol Car Allocation Model assumes that calls arrive randomly and service times are probabilistic.

Of course, none of the above assumptions will be precisely correct in practice. However, experience in several cities has shown that use of a more accurate model (such as a simulation model) would lead to the same allocations as one derives with the Patrol Car Allocation Model, or at most a difference of one or two patrol cars at certain times or places. Indeed, errors that arise in collecting data often lead to greater inaccuracies than the approximations incorporated in the model's program.

History of Use

The Patrol Car Allocation Model was designed by The New York City-Rand Institute after a careful review of various patrol car allocation programs that have been previously used by police departments. Of these, the best known ones are the Law Enforcement Manpower Resource Allocation System (LEMRAS), a product of the IBM Corporation, and the Resource Allocation Program described in *Urban Police Patrol Analysis.*[8] The Patrol Car Allocation Model incorporates many of the best features of all of these programs, together with several improvements.

Among the cities whose police departments have used either this program or one of the earlier patrol car allocation programs are the following: Atlanta, Georgia; Kansas City, Missouri; Los Angeles, California; New York City; Rotterdam, The Netherlands; St. Louis, Missouri; and Seattle, Washington.

[8] R. Larson, *Urban Police Patrol Analysis*, MIT Press, Cambridge, Mass., 1972.

Resources Needed for Implementation

Successful use of the model requires little or no knowledge of computers by the user, who controls the program with a sequence of simple commands. These are punched on cards if the program is being run in batch mode, or they are entered at an on-line terminal when the program is being used interactively.

The program can be installed for batch operation on any computer system having a Fortran compiler and at least 160K bytes of core storage. For such installations, it is not necessary for any of the agency's staff to understand the Fortran language. To install the program for interactive operation, the user must have access to a computer system that supports interactive programs and must make four minor modifications that are clearly indicated in the program description. To access the program via one of the commercial time-sharing services on which it is available, the user needs only a computer terminal that can be coupled to a telephone line.

The amount of effort required to prepare a data base for the model depends primarily on the amount of information currently available to the department concerning calls for service and other unavailabilities of patrol cars. If available data are to be converted manually into a form suitable for input into the model, about one man-day of effort per geographic command will be required. If a computer program is to be written to perform the conversion, this will require about three man-weeks of work initially, but then subsequent updating of the data base will be easy.

If the department has not previously collected information from dispatchers concerning the availabilities of patrol cars, several man-months should be allowed for preparing a data base.

Persons with the skills to set up and run the model and analyze its output are likely to be found in most municipal governments. Little or no outside assistance should be required.

Computation Cost

The cost of running the program will vary from installation to installation. It will also vary from run to run, depending upon how many user commands are entered and how many geographic commands and time periods are being considered simultaneously. In most cases the cost per run will be between $1 and $10. In general, the model is an inexpensive program to operate and compares favorably with any other program that could be used to answer similar policy questions.

Documentation

Three reports have been prepared to document the Patrol Car Allocation Model: a nontechnical introduction, a user's manual (which includes the mathematical details underlying the model's calculations), and a program description (which gives file specifications and installation instructions). They are:

Jan Chaiken and Peter Dormont, *Patrol Car Allocation Model: Executive Summary*, R-1786/1-DOJ, The New York City-Rand Institute, September 1975.

Jan Chaiken and Peter Dormont, *Patrol Car Allocation Model: User's Manual*, The New York-City-Rand Institute, R-1786/2-HUD/DOJ, September 1975.

Jan Chaiken and Peter Dormont, *Patrol Car Allocation Model: Program Description*, The New York City-Rand Institute, R-1786/3-HUD/DOJ, September 1975.

G. THE HYPERCUBE QUEUEING MODEL

Structure

The Hypercube Queueing Model ("the hypercube model") was developed to aid in the design of police patrol beats[9] and to analyze other questions related to specific geographic details of patrol operations within a command. It is also useful for planning the locations and response districts for ambulances and fire companies, but it has been primarily applied to police operations. The Patrol Car Allocation Model (see the preceding section) cannot be used to obtain information on individual patrol cars or specific incident locations because it calculates *average* performance measures for an entire command, and it estimates the averages from approximate formulas that ignore variations within a command.

The hypercube model distinguishes two conditions for each emergency unit: it is either available for dispatch or unavailable. The *state* of the entire collection of emergency units is described by specifying the condition of each unit. The hypercube model calculates how often each state will occur using equations from queueing theory. In one mode of operation, the program solves the queueing equations *exactly*. (This is practical for up to 15 units.) In a second mode, the program solves the equations *approximately*. For 15 units or less, the approximate mode is less expensive to run on the computer than the exact mode; for more than 15 units, it is necessary to use the approximate mode. (The errors introduced by using the approximate mode are almost always under 5 percent, and typically under 2 percent.)

Once the program knows the probability with which each state will occur, which unit responds to every location in each state, and what the resulting travel times would be, it can calculate all the performance measures in the output.

Uses

The hypercube model was developed specifically to be used by police departments in designing beats. For this purpose it is a substitute for more complex computer programs, such as simulation models (see Sec. H, below). It can also be used by other emergency service agencies to determine locations and response areas for its vehicles. It is a descriptive model, which shows the consequences of proposed deployment policies in terms of a large number of performance measures, including disaggregated measures such as the workloads of individual units and the travel times to every potential incident location.

The model can help the police planner to identify patrol beat designs that accomplish one or more of the following objectives:

- Balancing workloads among units;
- Equalizing response times among different parts of a command;

[9] A *beat* is the area in which a specific patrol car has preventive patrol responsibility. Other commonly used names for beats are "patrol areas" or "sectors."

- Minimizing average response time for the entire command;
- Minimizing the extent to which patrol units are dispatched outside their assigned beats.

In general, it is impossible to achieve all of these objectives simultaneously, so the model assists the planner in finding acceptable compromises. It provides him with detailed information about the performance measures, which permits him to identify the failings of any proposed beat design and leads him to construct a sequence of improvements, ultimately resulting in an acceptable design

The hypercube model will permit analysis of designs in which beats overlap, as well as traditional nonoverlapping designs. This capability is particularly important to departments that wish to minimize or reduce the extent of out-of-beat dispatching. Many departments have recently introduced "team policing" or other allocation plans in which several units share responsibility for an area that is larger than a traditional patrol beat. These plans constitute various forms of overlapping beats, and the areas of responsibility for each team can be designed using the hypercube model.

The ambulance system planner can use the model to explore the consequences of alternative pre-positioning sites for his ambulances and alternative districts of primary responsbility for each. It is especially useful for ambulance services in which many units (say, more than 10 percent) are often unavailable If this is not the case then the Firehouse Site Evaluation Model (Sec. D) is more appropriate.

It is more difficult for a *fire department* having 10 percent or more of its fire-fighing units busy at one time to decide whether or not to use the hypercube model for the evaluation of alternative arrangements of fire companies than it is in the case of ambulance agencies. This is because the hypercube model operates on the assumption that only one fire-fighting unit is ordinarily dispatched to each incident. If, by considering engine companies and ladder companies separately, this is a reasonable assumption, then the hypercube model is appropriate. Otherwise, a fire department in which many units are busy at once would have to use a more complicated model, such as the Simulation Model of Fire Department Operations (Sec. E, above), for final evaluation of a proposed configuration of stations. In any event, if a fire department is considering changes in dispatch policy or in policies related to the relocation of units when coverage is inadequate, as well as changes in station locations, the simulation model will be needed and the hypercube model should not be used.

Data Requirements

The data base for the hypercube model includes the following information (in describing the data we will assume that the model is being used to aid in the design of police patrol beats):

- The relative arrival rates of calls for service from small geographical areas (called *atoms*), which are typically no larger than a few city blocks, for each time period for which a beat design is desired (each *beat* is a collection of atoms);
- The average service time per call;
- Geographical coordinates of the center of each atom;
- Average travel speeds in both the predominantly north-south and east-west directions (or the travel times between specific pairs of atoms);

- A description of the manner in which units perform preventive patrol. There are three options: (a) a list is input giving the fraction of time each patrol unit spends in each of the atoms in its beat; (b) each unit will patrol its atoms in direct proportion to call volumes; (c) each unit will divide its patrol time uniformly among the atoms in its beat;
- A description of the dispatching policy, including the preferred order in which vehicles are dispatched to calls in each atom, and whether queueing of calls is permitted.

Output

The hypercube model will describe all the following characteristics of a given beat design.

For the entire city or part of the city under study:

- Average travel time to an incident;
- The difference in *workload* (measured by the fraction of the time the unit is busy handling incidents) between the busiest and least busy unit;
- Percent of dispatches that take units outside their beats.

For each patrol car:

- Average travel time to the incidents to which it responds;
- Its workload;
- Percent of its dispatches that take it outside of its beat.

For each beat:

- Average travel time to incidents in the beat;
- Percent of incidents handled by a unit assigned to the beat.

For each atom:

- Average travel time to incidents in the atom;
- Percent of incidents in the atom that are handled by each of the units;
- The average number of times per hour that a patrol car passes a randomly chosen point in the atom while on patrol.

Assumptions

The primary assumptions of the hypercube model are:

- The service region can be divided into atoms within which the workload is uniformly distributed.
- Calls for service are generated within each atom according to a Poisson process that is independent of the generation process in all other atoms.
- The service time for each call (including travel time and on-scene time) is chosen from the same exponential distribution and is independent of the identity of the server, the location of the caller, and the state of the system.
- Exactly one unit is dispatched to every call.
- If a unit is available within the service region when the call is received, the call will be serviced immediately. If no unit is available, the call either

enters a queue with other backlogged calls, or it leaves the system and is assumed to be serviced by some back-up system—e.g., by a car from a different geographic command (this is a user option). Queued calls are serviced in the order in which they arrive.

- The dispatcher has an ordered list of preferred units to dispatch to calls from each atom, and he always dispatches the available unit that is most preferred (highest on the list).
- The location of each response unit, while not servicing a call, is known (at least statistically).
- If the travel times between atoms are not supplied to the program, the times will be calculated based on right-angle distances between the atoms and constant (user supplied) average speeds in each of the coordinate directions.

History of Use

The theoretical development and computer program design of the Hypercube Queueing Model began in 1971. This work was funded jointly by HUD's contract with The New York City-Rand Institute and a National Science Foundation grant to the Massachusetts Institute of Technology. The model was first used in Boston to help in the redesign of police sector boundaries as part of a massive manpower reallocation program, "The Maximum Response and Patrol Plan," implemented by the Boston Police Department in September 1973. Since then it has been used to analyze beat designs of police departments in at least twenty other cities, including Arlington and Quincy, Massachusetts, and New Haven, Connecticut.

In Arlington an administrator in the city manager's office, while studying the Police Department's operations, found that the workload by sector was unbalanced. Using the hypercube model he developed three acceptable sector designs. One was selected and is about to be implemented.

In Quincy an eighteen-month project was carried out that used the hypercube model to analyze alternative sector designs. It is estimated that the new sector designs implemented in Quincy will let the Police Department operate for at least two more years without requiring expansion of the patrol force.

The primary objective of the work in New Haven was to transfer the hypercube model to personnel in the New Haven Department of Police Services for use in analyzing beat design problems. As a result, the Department's statistician was trained in the use of the model, and the program was installed on the Yale University computer system.

Resources Needed for Implementation

As the work in New Haven showed, the hypercube model can be easily transferred to other cities. (The term *transfer* refers to enabling a user to construct an appropriate data base and making the computer program operate properly on the user's computer system.) Transfer requires the efforts of an analyst who understands the model and who can supervise the construction of the data, the running of the model, and the interpretation of the output.

The length of time required to collect data for use in the model depends on the following:

- Whether or not the agency has previously recorded the identity of the atom (or equivalent geographical information) for each incident in computer-readable form. (This information is needed to calculate the relative call rates for the atoms.)
- Whether or not the coordinates of atoms on a grid map of the city or, as a substitute, the times required to travel between each pair of atoms, are known.

If both are already available, the hypercube model can be used after at most two man-weeks of data preparation. Otherwise, the agency should plan on about four man-months for data collection.

The computer program for the hypercube model is written in PL/I, so an agency wishing to use the program must have access to a compiler for this language. However, it is not necessary for any of the agency's staff to understand the PL/I language. All options available with the program are chosen by means of input cards, so there is never any need for an agency to make changes to the program statements themselves before using the model.

The core storage requirements depend on the number of atoms being considered and whether the exact or approximate model is being used. To model a city with 120 atoms on an IBM System 370 computer, the exact hypercube program required core storage ranging from 120K bytes for a small number of emergency units up to 500K bytes for 15 units. The approximate model never required more than 200K bytes.

Computation Cost

The cost of each run will vary from installation to installation depending on the price structure, but a special feature of the program permits rapid determination of the costs of each stage of the calculations. The primary influences on cost are:

- Whether the user chooses the exact hypercube model, which can be quite expensive (but less expensive than a simulation model), or the approximate model, which is inexpensive;
- The number of emergency units to be considered (which cannot be more than 15 when using the exact model, but is essentially unlimited in the approximate model);
- The number of atoms in the city or part of the city to be modeled.

Using the MIT Information Processing Center's IBM 370/165 computer to model a city with 120 atoms and 15 emergency units, the cost for one run of the exact model was \$100. However, with the approximate model the cost for each run was under \$10 in all realistic cases tried. For most typical runs, the cost was about \$1.00.

Documentation

The mathematical development of the exact hypercube model is given in:
Richard Larson, *A Hypercube Queuing Model for Facility Location and Redistricting in Urban Emergency Services*, The New York City-Rand Institute, R-1238-HUD, March 1973.

The mathematical development and verification of the approximate hypercube model is described in:

Richard Larson, *Urban Emergency Service Systems: An Iterative Procedure for Approximating Performance Characteristics*, The New York City-Rand Institute, R-1493-HUD, January 1974.

The batch version of a computer program that implements both the exact and approximate hypercube models is documented in three reports:

Jan M. Chaiken, *Hypercube Queuing Model: Executive Summary*, R-1688/1-HUD, The New York City-Rand Institute, July 1975.

Richard Larson, *Hypercube Queuing Model: User's Manual*, The New York City-Rand Institute, R-1688/2-HUD, July 1975.

Richard Larson, *Hypercube Queuing Model: Program Description*, The New York City-Rand Institute, R-1688/3-HUD, July 1975.

A program has been written at MIT that enables the hypercube model to be used in an interactive environment. It was designed so that a police planner with little or no computer experience can sit at a remote terminal and "converse" with the program in English. A short, nontechnical introduction to this program is:

Richard W. Weissberg, *Using the Interactive Hypercube Model*, Innovative Resource Planning in Urban Public Safety Systems, Massachusetts Institute of Technology, Cambridge, Massachusetts, TR-17-15, June 1975.

In work at M.I.T., the approximate hypercube model has been integrated into two computer programs that can be used to generate good beat designs (the hypercube model itself only describes the consequences of implementing a given design). One program modifies patrol beats so that workload imbalances among beats are minimized. The other minimizes imbalances in average travel distances among beats. Both programs are iterative (moving from one design to another by switching one atom at a time). They therefore generate not only a final design, but also data about all intermediate designs. The two programs are described in:

Kenneth Chelst, *An Interactive Approach to Police Sector Design*, Innovative Resource Planning In Urban Public Safety Systems, Massachusetts Institute of Technology, Cambridge, Massachusetts, WP-03-74, March 1974.

Case studies describing how the hypercube model was used in various cities are presented in:

Richard Larson, *Illustrative Police Sector Redesign in District 4 in Boston*, Urban Analysis, Vol. 2, 1974, pp. 51-91.

Kenneth Chelst, *Implementing the Hypercube Queueing Model in the New Haven Department of Police Services: A Case Study in Technology Transfer*, The New York City-Rand Institute, R-1566/6-HUD, July 1975.

James Jarvis, Mark McKnew, and Larry Deetjen, *Data Collection and Computer Analysis for Police Manpower Allocation in Arlington, Massachusetts*, Innovative Resource Planning in Urban Public Safety Systems, Massachusetts Institute of Technology, Cambridge, Massachusetts (to appear).

Quincy Police Department, *Application of the Hypercube Model, Sector Design Analysis*, Quincy Police Department, Quincy, Massachusetts, 1975.

H. A SIMULATION MODEL OF POLICE PATROL OPERATIONS

Structure

The police patrol simulation model (a completely separate model from the fire simulation) simulates the activities of radio-dispatched patrol cars, including beat cars, supervisory cars, and other special cars. It imitates step-by-step the activities of the patrol cars, tracking each of a large number of incidents through a series of events. The events include receipt of the call itself, the dispatch of one or more patrol cars, their arrival at the scene, work at the incident, completion of the job, and return of the cars to patrol and availability for another dispatch. The simulation acts much like an "all-knowing" dispatcher who can keep in mind at all times the location and status of all the patrol cars and incidents, but who does not pay attention to police tactics or activities at the scene. The simulation imitates the patrol operations in a region of a city having one or more patrol cars on duty. In New York City it has usually been used to imitate operations within a geographic command in which between 5 and 15 patrol cars are placed on duty.

The simulation is the most detailed and sophisticated of the police deployment analysis models, and requires the largest data base. However, it can provide more complete and reliable statistics than can be obtained from simpler models.

The simulation model was designed to include most aspects of patrol car operations that are necessary to evaluate alternative deployment policies. Accordingly, the model includes a geographic representation of the part of the city being simulated, travel times, location of potential incidents, and the patrol assignments of the cars. The simulation can also represent the discovery of incidents by cars on patrol ("pick-up jobs"). In addition, it can imitate the way patrol cars take meal breaks and how they go out of service for other reasons.

Uses

The simulation model should not be used for certain purposes. It should not, for example, be used to get rough estimates of the current performance of a patrol force. Nor should it be employed to explore preliminary ideas about changes in the number of patrol cars assigned, dispatch policy, or designs of response districts or patrol beats. Other less precise but easier to use models (see Sec. F and G, above) are available for these purposes. Moreover, the simulation does not directly suggest any changes as being desirable; it simply predicts what would happen if a proposed change were implemented. Thus its main use is for careful evaluation of a proposed deployment policy that has already been analyzed in some detail. The simulation was designed principally for evaluating and comparing police department policies that differ with respect to:

- The number of patrol cars on duty at various times of day and in various seasons;
- The beat assignments of the patrol cars;
- The number of patrol cars that respond to various kinds of calls for police service;

- The manner in which calls are queued and particular units are dispatched to each call depending on the priority and location of the incident;
- The circumstances under which patrol cars are relocated to cover another car's beat;
- How the command is divided into beats;
- The size of the command (e.g., what would happen if several commands were combined into a single dispatch command region).

Data Requirements

There are two sets of data needed to run the simulation. One data set contains a stream of calls for service that has been generated outside the program (and can be historical call data). Associated with each call for service is the time of occurrence, its priority and location, and the time required to service the call.

The other data set specifies the geographic configuration of the region being simulated, the patrol unit assignments and such initial parameter values as the response velocities, meal times, length of a tour of duty, and simulation duration. In particular, the information required for each incident location includes:

- The beat to which it belongs;
- The (x,y) coordinates of the incident location.

The region being simulated is partitioned into beats for purposes of patrol and dispatching. For each beat the following information is required:

- The patrol cars with primary responsibility in the beat (there may be more than one);
- A list of cars in the order that they would be dispatched to an incident in the beat.

A certain number of patrol cars are assigned to the region being simulated. For each, the following information is required:

- The beats that it is assigned to patrol;
- The center of its patrol region [(x,y) coordinates],
- The time during a tour when it takes its meal break.

Output

The performance characteristics produced by the simulation fall into the following three categories:

- *Response time measures:* the mean, variance, and distribution of response times are gathered by job priority and by beat.
- *Queueing Delays:* the mean, variance, and distribution of the number of calls in the dispatcher's queue and their waiting times are displayed by job priority. The average and variance of waiting times are shown for all jobs and for only those jobs that were delayed.
- *Car activity:* the proportion of time each patrol unit spends working (both on patrol and out of service) is displayed, as well as the number of jobs handled (both within and outside of beat) by each car, and the mean,

variance, and distribution of the number of units available to respond to calls.

Assumptions

A geographic command is modeled as a collection of discrete points at which calls for service occur. The model assumes that units travel from point to point along a rectangular network of streets at a constant velocity, which depends on the priority of the job.

To imitate the continuous movement of patrol units in the simulation would be very costly in terms of computing times. Hence, the movement of patrol units is simulated as follows:

- If a unit completes a job in its beat it is placed "on patrol" at the location of the job just completed.
- If a unit completes a job outside its beat and is not immediately dispatched to another job, it returns to the center of its beat and is placed "on patrol" at that point.

It should also be noted that the seriousness and duration of a job may actually depend on the speed with which a patrol car gets to the scene. Since this relationship is unknown, the simulation assumes that job duration is unaffected by the speed of response. Moreover, this version of the simulation includes no provision for dispatcher delay (delay in dispatching caused by congestion at the dispatcher's station rather than by the unavailability of patrol cars).

History of Use

The police patrol simulation model was programmed, tested, and refined during 1972 and 1973 by members of the staff of The New York City-Rand Institute with the help of personnel from the New York City Police Department. Since then it has been applied to the analysis of police deployment policies in New York City. It was initially used on data from one precinct to investigate the effect on performance that would arise from varying the number of cars on duty. Later it was used to determine the benefits that could be expected from combining two precincts into a single command. Another application was to evaluate the improvement in performance that could be expected from using a car locator system to determine the closest available car to a given incident location.

In 1975 the simulation was modified slightly and used by a team of planners in the Seattle Police Department.

Resources Needed for Implementation

This simulation model requires significantly fewer input data than the fire simulation model. However, it requires more data than any of the other police deployment models. Using the simulation requires data processing skills to install the model on a computer, statistical expertise for analysis of the output data, and programming skills to make the necessary changes in the simulation. Most police departments do not possess staffs with these skills and will require the assistance

of trained personnel from outside the department. In New York, personnel from The New York City-Rand Institute aided the Police Department in using the simulation. However, a team of civilian analysts in the Seattle Police Department were able to implement the model with little outside assistance.

The simulation requires a moderately large computer system. The minimum core storage requirements are 164K bytes for compilation and 142K bytes to run the program. To run the program, the system should also have an auxiliary storage device, such as a tape or disk drive. The simulation requires a SIMSCRIPT II.5 compiler, a software package that is commonly available at university and commercial computation centers, but is unlikely to have been acquired by a city's data processing unit. If the compiler is not furnished by Consolidated Analysis Centers, Inc., additional programming changes may be required.

A police department considering use of the simulation should plan on allowing at least three months between receiving the program and final analysis of policies. About one-half man-year of effort by analysts and department staff personnel together is required to prepare and use the model properly.

Computation Cost

On an IBM Model 360/85, approximately 190 calls for service can be processed in one second of computer time. Using the computing facilities of a commercial service bureau, the typical computer charge for a run simulating about 1700 calls was approximately $13. However, the cost of a simulation run may vary greatly from installation to installation. The major portion of the cost of using the simulation is likely to be in the preparation of the input data, rather than in computer charges.

Documentation

Two reports have been published that document the patrol simulation model: a nontechnical introduction, and a user's manual (which includes a complete listing of the program, its input data requirements and output reports). They are:

Peter Kolesar and Warren E. Walker, *A Simulation Model of Police Patrol Operations: Executive Summary*, The New York City-Rand Institute, R-1625/1-HUD, March 1975.

Peter Kolesar and Warren E. Walker, *A Simulation Model of Police Patrol Operations: Program Description*, The New York City-Rand Institute, R-1625/2-HUD-NYC, February 1975.

In 1974 the police patrol simulation model was validated by comparing the simulation output with actual data collection during two complete tours in one New York City precinct. The validation effort is described in:

Thomas B. Crabill, Warren E. Walker, and Peter Kolesar, *Validation of a Police Patrol Simulation Model*, The New York City-Rand Institute, P-5464, June 1975.

III. DEPLOYMENT ANALYSIS CASE STUDIES

The HUD contract under which the models discussed above were documented, falls within HUD's Community Development and Management Research Program. The program is designed to introduce local managers to useful and usable management tools, and to develop a local capacity to deal with problems. An important element emphasized by the program is the testing of new management methods in representative communities to determine their usefulness. In line with this objective, we field tested the models we had developed for emergency service deployment analysis in several cities throughout the country. In each city we worked jointly with a local project team in order to enable them to understand the methods, make the decisions, and perform similar analyses in the future without our help.

The test cities were carefully chosen. Over fifty cities indicated their desire to participate. Seven were chosen, representing a mix of city sizes and emergency services. Fire company deployment problems were studied in Denver, Colorado, Yonkers, New York, Jersey City, New Jersey, Wilmington, Delaware, and Trenton, New Jersey. Police allocation and sector design problems were studied in New Haven, Connecticut. Ambulance deployment problems were studied in Washington, D.C.

The work performed in each of these cities besides Washington, D.C. is discussed below. (The Washington, D.C. results were not implemented and no final report was published.) The discussion of each case concentrates on the following seven aspects of the study:

(1) The characteristics of the city and the emergency service agency. For the city, this will include such things as its population, area, budget, etc. For the agency, it will include its budget, number of vehicles, number of calls for service, etc.

(2) The deployment issues that the study addressed. We found that, because of the financial crises that all cities are now facing, the issues of paramount importance were: (a) How many emergency service units are needed to achieve various service levels? (b) Where should those units be located?

(3) The people who served on the project team. As mentioned above, the local team members were responsible for doing much of the work and for drawing up the recommendations. (We have found that this approach offers the best chance for getting the results of the study implemented.)

(4) The deployment model or models used in the study. At least one of the models described in Sec. II was field tested in each city.

(5) The results of the study.

(6) The degree to which the recommendations arising from the study have already been implemented.

(7) Sources of further information on the study.

A. THE DENVER (COLORADO) FIRE DEPARTMENT

Characteristics of the city

- 1970 population: 515,000
- Area: 110 square miles
- Population per square mile: 5406
- 1974 general fund budget: $142 million (excluding public school expenditures)
- Budget per capita: $276

Characteristics of the Fire Department

- 1974 operating budget: $14 million
- Budget per capita: $27.20
- Fire fighters: 929
- Firehouses: 27
- Engine companies: 27
- Ladder companies: 17
- 1972 alarms: 17,968 total, 2,048 structural (11%), 4169 false (23%), 6072 nonfire emergencies (34%)

Deployment Issues Addressed

The primary deployment objective of the Denver project was to develop recommendations for alternative firehouse configurations that would provide approximately the same level of fire suppression service at a lower cost. The project also considered the possibility of using new types of apparatus.

Composition of Project Team

The project was carried out by a large project team: operations research analysts, computer specialists, and statisticians from the College of Business and Administration, University of Colorado; management and budget analysts in the Budget and Management Office of the City and County of Denver; and members of the Denver Fire Department. The team was directed and administered by the Deputy Finance Director of the City and County of Denver and the Director of the Denver Urban Observatory. Further, a Policy Review Committee was formed to guide the activities of the research team. This Policy Review Committee consisted of the Finance Director of the City and County of Denver, the Denver Fire Chief, the Dean of the Graduate School of Public Affairs of the University of Colorado, an Administrative Assistant to Denver's Mayor, and the Director of Denver's Career Service Authority.

Model(s) Used

A unique feature of this case study is that the Institute's role in the analysis was limited to providing a training course, documentation, computer programs, and occasional guidance. The project team had the technical competence and freedom to accept, reject, or modify any of the Institute's models as appropriate in the Denver

context, to apply models available from organizations other than the Institute, and to design its own models.

As a result, the only model described in Sec. II that was used directly in the project was the Fire Operations Simulation Model. However, a regression program similar to the Travel Time Analysis Program was used to establish the relationship between travel time and travel distance, and a model similar to the Firehouse Site Evaluation Model, which they called the Station Configuration Information Model (SCIM), was used to compare alternative arrangements of firehouses.

The regression program that they used instead of the Travel Time Analysis Program fit linear, square-root, and logarithmic curves to the data. The relationships that were used in the project were:

$$T = .30 + 2.01D \text{ in the downtown area,}$$

and

$$T = .44 + 1.70D \text{ in the remainder of the city,}$$

where D is the travel distance in miles and T is the estimated travel time in minutes. When the experimental data were used in the Travel Time Analysis Program, the best square-root/linear fit using all the data was given by

$$T = \begin{cases} 1.95\sqrt{D} & D \leq 1.40 \\ .62 + 1.53D & D \geq .40. \end{cases}$$

The team also developed an integer programming model for generating alternative arrangements to try in the SCIM. The integer programming model and the SCIM were used to select a small number of acceptable configurations based on the assumption that fire companies would always be available in their firehouses for dispatch to incoming alarms. These configurations were then tested with the Fire Operation Simulation Model to see how each would perform when company unavailability was taken into account.

Summary of Results

The project produced recommendations for the location of engines and ladders in Denver that left the level of service almost the same, with the reduction of five companies—from 44 suppression companies to 39 suppression companies (a reduction of 85 fire fighters). These reductions are scheduled to be accomplished over a period of time by the construction of firehouses, abandonment of existing houses, and equipment changes. It is estimated that they will eventually save the city $1.25 million yearly.

One guideline specified by the city for the implementation of these proposed changes is that there shall be no layoffs due to a reduction in the number of fire companies. Hence, attrition becomes the determining factor for the rate of company reduction. An eleven-stage timetable was developed that would result in all changes being made by January 1979.

Status of Implementation

Denver's 1975 budget and the Mayor's proposed budget for 1976 both reflect the recommendations of the project. One fire station has already been closed and one station rebuilt and reopened, as provided for in stages 1 and 2 of the timetable. A consolidation of two stations, recommended as part of the third stage, has already taken place, but the elimination of an engine company, the other part of the third stage, has not yet been accomplished. The Mayor's budget for 1976 calls for the elimination of 49 fire fighters' positions (three fire companies).

References

The deployment analysis carried out by the Denver project team is described in

Thomas E. Hendrick, Donald R. Plane, et al., *An Analysis of the Deployment of Fire-Fighting Resources in Denver, Colorado,* The New York City-Rand Institute, R-1566/3-HUD, May 1975.

Information on additional aspects of the project, including an evaluation of the information needs of the Department and an assessment of the need for a computer-assisted dispatch system, is contained in:

Thomas E. Hendrick, and Donald R. Plane, et al., *Denver Fire Services Research Project Report; Feasibility Test of Applying Emergency Service Deployment and Facility Location Methods to Assist in Municipal Budget Decisions in the Fire Service,* Denver Urban Observatory, Box 2483, University Center, 4200 E. 9th, Denver, Colorado 80220, 1974.

An executive summary report was prepared that gives an overview of the project. Called "Policy Analysis for Urban Fire Stations: How Many and Where," it is available from the Denver Urban Observatory at the address given in the last reference.

B. THE JERSEY CITY (NEW JERSEY) FIRE DEPARTMENT

Characteristics of the city

- 1970 population: 259,613
- Area: 15.1 square miles (of which only 9.8 square miles are developed)
- Population per square mile: 17,193
- Population per square mile of developed land: 26,491 (which makes it the second most densely populated city of over 100,000 people in the U.S.)
- 1974 operating budget: $59,089,687
- Budget per capita: $228

Characteristics of the Fire Department

- 1974 operating budget: $12,051,903
- Budget per capita: $46.42
- Fire fighters: 712
- Firehouses: 17

- Engine companies: 18
- Ladder companies: 11
- Rescue companies: 2
- 1973 alarms: 11,993 total, 2,028 structural (17%), 5,126 false (43%)

Deployment Issues Addressed

The major deployment objective was to determine the appropriate number and location of fire companies for Jersey City over a ten-year planning period. The analysis also considered how the companies should be manned, what types of fire-fighting equipment should be used, and what the initial dispatch policy should be.

Composition of Project Team

The project team consisted of three members of the Jersey City Fire Department; a Captain directed the team, and a Battalion Chief and Captain provided full-time support. In addition, the Director of Public Safety, Chief of the Department, and a Deputy Chief reviewed the progress of the project.

Model(s) Used

The relationship between travel distance and travel time for fire companies in Jersey City was determined using the Travel Time Analysis Program The best estimates of travel time were found to be given by the square-root function

$$T = 2.68\sqrt{D},$$

where T is the travel time in minutes and D is the travel distance in miles.

Using the Parametric Allocation Model, a gross determination was made of what regions in the city should lose companies if companies were to be eliminated and how the remaining companies should be allocated to regions of the city. Specific locations for new firehouses were evaluated using the Firehouse Site Evaluation Model.

Summary of Results

Several deployment options of similar cost were developed and compared to each other and to the current deployment of fire-fighting resources. One was based on a reduction in the number of fire companies with an increase in fire company manning. Another centered on the use of consolidated firehouses in which two engines would be stationed. A third involved the deployment of minipumpers. In addition, several new dispatching policies were assessed. These efforts led to the following conclusions:

- There are currently a sufficient number of fire-fighting units deployed in Jersey City to respond to higher alarms or simultaneous alarms and to provide adequate coverage throughout the city over the next ten years.
- The personnel currently deployed on some units could be advantageously redeployed to minipumpers, or could be used to increase the manning levels of a small number of units.

- Stationing two engine companies in one consolidated firehouse is inefficient with respect to travel times to fires.
- There are a number of key sites within the city where firehouses should be strategically located regardless of future changes in population or land use. Firehouses are currently located on most of these sites.
- The current dispatching policy is satisfactory.

Status of Implementation

No deployment changes have yet been implemented as a result of this study. The Fire Department is currently analyzing the costs and benefits of the various options developed. However, the study has led to three important results.

(1) The study confirmed the suitability of a choice that had already been made for the site of a new firehouse.
(2) A computerized fire incident reporting system was implemented in which incidents are recorded in computer-readable form as they occur. This will facilitate the updating of data bases for further analysis as conditions change.
(3) Two of the Institute's deployment models (the Parametric Allocation Model and the Firehouse Site Evaluation Model) are now in routine use by the local project team (in fact, they used the siting model, without any outside assistance, to analyze the deployment of Jersey City's ambulances).

References

A complete description of the Jersey City project is presented in:

Kenneth Rider, Jack Hausner, et al., *An Analysis of the Deployment of Fire-Fighting Resources in Jersey City, New Jersey,* The New York City-Rand Institute, R-1566/4-HUD, August 1975.

C. THE TRENTON (NEW JERSEY) DIVISION OF FIRE

Characteristics of the city

- 1970 population: 104,438
- Area: 8.46 square miles
- Population per square mile: 12,345
- 1975 operating budget: $29,494,070
- Budget per capita: $282

Characteristics of the Fire Division

- 1975 operating budget: $4,419,560
- Budget per capita: $32
- Fire fighters: 290
- Firehouses: 10
- Engine companies: 9

- Ladder companies: 4
- 1973 alarms: 3650 total, 895 structural (25%), 1272 false (32%), 567 nonfire emergencies (16%)

Deployment Issues Addressed

The immediate concern of the project was the selection of a new site for an engine company whose quarters had become so dilapidated that they were unusable. This situation provided an opportunity for the city and the Fire Division to undertake a comprehensive analysis and re-examination of the number of fire companies needed and where they should be located. The project focused on the development of deployment policies to improve the city's fire protection by use of the the existing fire-fighting resources and to obtain good protection with fewer resources.

Composition of Project Team

The local project team was directed by a management analyst in the Business Administrator's office. The team included the Chief and a Deputy Chief of the Trenton Fire Division and several members of Trenton's Department of Planning and Development.

Model(s) Used

The relationship between travel distance and travel time for Trenton's fire companies was determined using the Travel Time Analysis Program. The best fit to the experimental data was provided by the square-root/linear function:

$$T = \begin{cases} 1.914\sqrt{D} & D \leq .31 \\ .533 + 1.719D & D \geq .31, \end{cases}$$

where D is the travel distance in miles and T is the travel time in minutes.

The Firehouse Site Evaluation Model was used to compare a large number of alternative arrangements of fire companies.

Summary of Results

An analysis of alternative arrangements of companies utilizing the existing fire-fighting resources resulted in arrangements that produced significant improvements in fire protection. For example, the citywide average first engine travel time was found to be 1.51 minutes with the existing arrangement. A new arrangement was found that would reduce this travel time to 1.29 minutes and produce a geographic pattern of travel times that is more consistent with the pattern of fire hazards.

Because the engine travel times with the existing arrangement of companies were already low, an analysis was made to determine the levels of fire protection that could be obtained with fewer engine companies. An arrangement of seven engine companies was found that would result in a level of fire protection that is

generally better than that being provided with the existing arrangement of nine engine companies

Status of Implementation

On May 19, 1975, the Mayor of Trenton presented the Trenton City Council with a set of recommendations for modifying the distribution of fire companies that were based on the results of the deployment analysis project conducted during the previous year The Mayor recommended eliminating two of the city's nine engine companies, closing seven of the existing ten firehouses, and building six new houses.

In his memorandum to the Council, the Mayor stated that the recommended changes would save the city "$740,000 a year and at the same time improve first- and second-due response time to fires." The Council has yet to act on the Mayor's recommendations.

An additional result of the project was that a capability to use the Firehouse Site Evaluation Model was transferred to the management analyst who directed the local project team, should the need arise for additional analysis in the future. As the Mayor's memo notes, the project "has left Trenton with the tools to analyze and systematically assess alternative sites for firehouses."

References

A complete description of the Trenton project is presented in:

Jack Hausner and Warren Walker, *An Analysis of the Deployment of Fire-Fighting Resources in Trenton, New Jersey,* The New York City-Rand Institute, R-1566/1-TRNTN, February 1975.

D. THE WILMINGTON (DELAWARE) BUREAU OF FIRE

Characteristics of the city

- 1970 population: 80,386
- Area: 12.9 square miles (of which only 8.5 square miles are developed)
- Population per square mile: 6231
- Population per square mile of developed land: 9413
- 1976 operating budget (excluding education): $24,689,000
- Budget per capita: $307

Characteristics of the Fire Department

- 1976 operating budget: $4,110,000
- Budget per capita: $51.13
- Fire fighters (authorized strength): 245[10]
- Firehouses: 8[10]
- Engine companies: 9[10]

- Ladder companies: 3
- Rescue squads: 1
- Fiscal year 1974 alarms: 2578 total, 1,034 structural (40%), 412 false (16%), 212 nonfire emergencies (8%)

Deployment Issues Addressed

The deployment analysis performed on this project focused on two questions: (a) How many engine companies should be deployed in Wilmington? (b) Given a certain number of engine and ladder companies, where should they be located? In particular, because of budget problems, the administration was interested in examining the possibility of phasing out one or more engine companies. The models were used to estimate the effects of such reductions on fire company travel times and workloads.

Composition of Project Team

Included on the project team were representatives of the city's administration, budget analysts, city planners, personnel from the Fire Department, and a leader of the fire fighters' union. In particular, the project was directed jointly by a planner in the Department of Planning and Development and an economist in the Mayor's Office. The Mayor's Public Policy Assistant and the Fire Bureau's head of planning and research were also involved from the beginning. In addition, the Commissioner of Public Safety, the Chief of the Bureau of Fire, his Deputy Chief for Administration, and, in the early stages, the president of the fire fighters' union reviewed the progress of the project and provided many useful suggestions.

The creation of the project team not only provided an ongoing analytic capability within the Wilmington government, but enabled the team members to understand the methodology, kept the analysis directed toward implementable policies, and provided a means by which various interests could be represented in the process of determinig new deployment policies.

Model(s) Used

The relationship between travel time and travel distance for Wilmington's fire companies was determined using an early version of the Travel Time Analysis Program. This version did not include the square-root/linear fit. So the analysis was performed using the following linear function:

$$T = 0.69 + 1.69D,$$

where D is the travel distance in miles and T is the travel time in minutes. Subsequent analysis of the data with the Travel Time Analysis Program found that the best square-root/linear fit was:

$$T = \begin{cases} 2.097\sqrt{D} & D \leq .35 \\ 0.627 + 1.791D & D \geq .35. \end{cases}$$

The Parametric Allocation Model was used to make a gross determination of what regions in the city should lose companies (if companies were to be eliminated) and

how the remaining companies should be allocated to regions of the city. Specific locations for new firehouses were evaluated using the Firehouse Site Evaluation Model. Over 100 different fire company arrangements were compared using the siting model. They included seven-, eight-, and nine-engine company options, and three- and four-ladder company options.

Summary of Results

The efforts on this project led to two important results:

(1) One of Wilmington's original nine engine companies was eliminated as a result of negotiations, producing an estimated saving of $240,000 per year with no loss of firemen's jobs and no perceptible reduction in fire protection. (No firemen lost their jobs because there had been 17 vacant positions. Minimum manning levels were being maintained by extensive use of overtime.)

(2) Plans were developed for the phased construction of six new firehouses to replace six existing firehouses over a four-year period. This plan is reflected in the capital program adopted by the City Council for the period beginning July 1975. Estimates from the siting model for the recommended configuration of eight engines and three ladders were compared to the estimates for the original nine-engine, three-ladder configurations. The comparison shows that the new configuration will maintain the balance between travel times in the various regions relative to demands and hazards in the regions; improve second-due engine travel times in many cases; and improve ladder travel times significantly in some regions—especially in the center city business area.

Status of Implementation

In October 1974, one of Wilmington's nine engine companies was placed out of service. The recommendations for the phased construction of six new firehouses for most of the remaining companies are reflected in the capital program adopted by the City Council for the period beginning July 1975. Design of the first of the new firehouses has been completed on schedule. The city has acquired land for the second proposed firehouse.

Another important result of the project is that the allocation model and siting model have been transferred to analysts in the Wilmington city administration for their use in reevaluating proposed firehouse site locations as conditions change in the future.

References

A complete description of the Wilmington project is presented in:

Warren E. Walker, David W. Singleton, and Bruce Smith, *An Analysis of the Deployment of Fire-Fighting Resources in Wilmington, Delaware,* The New York City-Rand Institute, R-1566/5-HUD, July 1975.

In this report, the project is described as a system analysis case study, from problem definition through data gathering, analysis of alternative deployment poli-

cies, and final results. It includes, as an appendix, a description of the labor-management negotiations that led to a reduction in the number of engine companies. A report available from the Office of the Mayor discusses the negotiations in detail: David Singleton, "Fire-Fighting Cost Reduction in Wilmington: A Case History."

E. THE YONKERS (NEW YORK) FIRE DEPARTMENT

Characteristics of the city

- 1970 population: 203,937
- Area: 18.0 square miles
- Population per square mile: 11,317
- 1976 operating budget (with education excluded): $71,811,272
- Budget per capita: $352

Characteristics of the Fire Department

- 1976 operating budget: $8,809,198
- Budget per capita: $43.20
- Fire fighters: 405
- Firehouses: 13
- Engine companies: 13
- Ladder companies: 7
- Rescue companies: 1
- 1971 alarms: 5572 total, 443 structural (8%), 1413 false (25%), 1787 nonfire emergencies (32%)

Deployment Issues Addressed

The immediate problem in Yonkers was that one of the Department's firehouses had been declared unsafe and was condemned by the city. This led the city to recognize the need for a careful analysis of the deployment policies of the Fire Department. The focus of the analysis was on ways in which the Department could improve its effectiveness by a better arrangement of its existing fire companies. The study also looked at the Department's dispatching policies.

Composition of Project Team

The local project team was led by an Assistant Chief of the Fire Department and included a Captain and a Lieutenant from the Department. The Acting Chief of the Department and the Director of the Bureau of the Budget periodically reviewed the progress of the project.

Model(s) Used

The Yonkers project was the first of the case studies completed. It was the initial testing ground for three of the Institute's models. An early version of the Travel Time Analysis Program was used to determine the relationship between travel time

and travel distance for Yonkers' fire companies. At that time, the program did not include the combination square-root/linear fit. Of the other functions, a linear function provided the best fit to the data:

$$T = 0.66 + 1.77\ D,$$

where T is the travel time in minutes and D is the travel distance in miles. Subsequent use of the Travel Time Analysis Program showed that the best square-root/linear fit was:

$$T = \begin{cases} 2.119\sqrt{D} & D \leq .35 \\ .627 + 1.791D & D \geq .35. \end{cases}$$

The Parametric Allocation Model was used to obtain an idea of how the existing fire companies should be reallocated to the various regions of the city to improve the Department's performance. Specific locations for new firehouses were evaluated using an early version of the Firehouse Site Evaluation Model.

Summary of Results

Sites for two new firehouses were recommended. The study also produced a set of further deployment options involving the addition and elimination of fire companies. The costs and benefits for each option were determined.

A change in the Department's dispatching policy was also recommended that would increase the number of companies sent to box alarms received between the hours of noon and midnight.

Status of Implementation

The recommendations of the project were presented to the Yonkers City Manager in December 1973. Since then, funds have been allocated in the budget for the two recommended firehouses and both sites were acquired by the city. The recommended dispatching policy was also implemented.

References

A complete description of the Yonkers project is presented in:

Jack Hausner, Warren Walker, and Arthur Swersey, *An Analysis of the Deployment of Fire-Fighting Resources in Yonkers, New York*, The New York City-Rand Institute, R-1566/2-HUD/CY, October 1974.

Details of how the Parametric Allocation Model was used to analyze the problem of reallocating engine companies in Yonkers appear in:

''der, *A Parametric Model for the Allocation of Fire Compa- al*, The New York City-Rand Institute, R-1646/2-HUD,

F. THE NEW HAVEN (CONNECTICUT) DEPARTMENT OF POLICE SERVICES

Characteristics of the city

- 1970 population: 137,715
- Area: 21.1 square miles
- Population per square mile: 6527
- 1973 operating budget: $72.7 million
- Budget per capita: $528

Characteristics of the Police Department

- 1973 operating budget: $6,326,072
- Budget per capita: $45.94
- Budget allocated to patrol services: $3,247,982
- Uniformed personnel: 420
- Assigned to patrol duty: 261
- Between 20 and 31 one-man patrol cars fielded per tour (usually 28)
- 1974 reported crimes: 10,555 total FBI Index crimes, 4032 burglaries, 6019 thefts (including motor vehicles), 6 murders

Deployment Issues Addressed

The objective of this project was to provide the New Haven Department of Police Services with the capability of using the Hypercube Queueing Model on their own to evaluate current and proposed deployment strategies. As part of this effort, the hypercube model was used to evaluate one of New Haven's existing beat designs, one command at a time, for combinations of commands, and for the city as a whole. For example, for this design, the model was used to find the distribution of patrol car workloads and average travel times, pinpoint the busiest and least busy patrol cars, and estimate the proportion of time each car would be busy servicing calls.

The computer programs that generate new beat designs to improve the balance of travel distances and patrol car workloads were also used to produce new beat designs for two commands.

Composition of Project Team

The local project team was jointly led by the Police Department's Director of Planning and the Assistant Director of Planning, and included two uniformed members of the Department (Captains) and the Department's statistician (a civilian). All of the members of the team were part of the Department's Planning and Budgeting unit.

Model(s) Used

The only model described in Sec. II that was used on the New Haven project was the Hypercube Queueing Model. The approximate version of the model was used. The project also made use of two computer programs for generating beat configura-

tions, each of which incorporates the approximate hypercube model as a subroutine. In each, the hypercube model is used to calculate the impact of the beat modifications on various performance measures. One of the programs generates beat designs that balance workloads; the other generates designs that balance travel distances (or travel times).

Summary of Results

The transfer of the models to the New Haven Department of Police Services (including the installation of the programs on Yale University's computer and the training of personnel to run and update the models) was completed. Examination of performance statistics for the current beat configuration indicated some sizable imbalances in travel distances and workloads.

Status of Implementation

The New Haven Department of Police Services recently made a decision not to use the hypercube model in the redeployment of its patrol personnel. They have developed some innovative crime-directed patrol strategies that led them to decide that, rather than modify the present beat configurations (which would have involved extensive use of the hypercube model), they would ignore, and eventually eliminate, the city's entire patrol beat structure.

References

The New Haven project is described in:

Kenneth Chelst, *Implementing the Hypercube Queueing Model in the New Haven Department of Police Services: A Case Study in Technology Transfer*, The New York City-Rand Institute, R-1566/4-HUD, July 1975.

This report focuses on the process of collecting the data required by the model and analyzing the model's output. It also includes illustrations of how various policy issues can be analyzed by varying the model's input parameters.

IV. DEPLOYMENT METHODOLOGY

The use of models is only one step in a deployment analysis study. Each of the other steps is also important and should not be skipped. The steps, summarized in Fig. 4, are:

(1) Identify the problem. For example, an old firehouse must be torn down. Where should its fire companies be moved?
(2) Decide on criteria with which to evaluate alternative policies; e.g , average travel times to fires, whether every alarm box is within a mile of the closest firehouse, company workloads, etc.
(3) Identify the objective of the analysis; e.g., a more equitable allocation of fire-fighting resources throughout the city.
(4) Select alternative policies to be analyzed; e.g., specify several possible arrangements of fire companies.
(5) Analyze each alternative in terms of the consequences that are likely if the alternative is actually implemented. (This is the step in which the models described in Sec. II will be used.)
(6) Compare the consequences of each alternative, using the criteria in step 4, and choose the one preferred (if none is desirable, return to step 4).
(7) Implement the chosen alternative.

The case studies described in Sec. III offer some assistance in performing a deployment study. However, the case studies deal with only one or two of the many emergency service deployment problems and are heavily concentrated on the fire service. Two general methodological reports have been written to help guide emergency service agency personnel, city officials, and system analysts through the steps of a deployment analysis study. They are:

Jan M. Chaiken, *Patrol Allocation Methodology for Police Departments*, The New York City-Rand Institute, R-1852-HUD, September 1975.

Jan M. Chaiken, Edward J. Ignall, and Warren E. Walker, *Deployment Methodology for Fire Departments: How Station Locations and Dispatching Practices Can Be Analyzed and Improved*, The New York City-Rand Institute, R-1853-HUD, September 1975.

The reports discuss the various strategic and tactical deployment issues associated with police and fire department operations, the measures of performance that are generally used to evaluate alternative deployment policies, and the models appropriate to use in analyzing each of the deployment issues. Both reports include a nontechnical description of the mathematical principles that underlie all of the deployment models. The report dealing with fire deployment analysis includes a chapter on the collection and analysis of the data needed by the various models.

Each report concludes with a discussion of the steps that should be followed in performing a well-managed deployment study. In addition to the classic steps in a system analysis study shown in Fig. 4, the discussion emphasizes the importance of finding people with the required analytical skills, assembling a representative

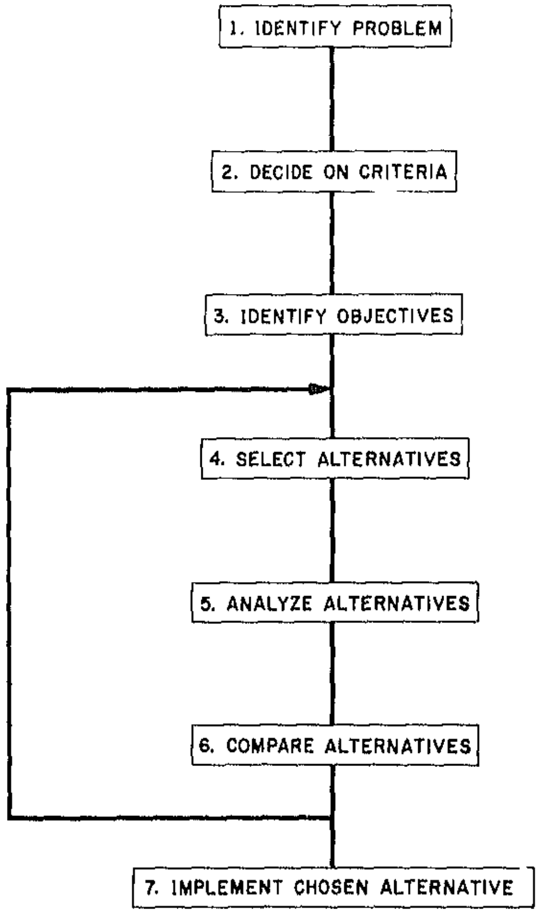

Fig. 4—Steps in a system analysis study

project team, and collecting and processing data. The reports also emphasize the importance of using a team approach in performing a deployment study. No policy change, however logically related to performance measures, can succeed if it is opposed for reasons that were not taken into account. Therefore, the team should include planners from the agency being studied, system analysts, administrators who will be called upon to make the final policy decisions, agency officials who will have to implement them, and possibly representatives of labor unions if negotiable issues are under study. Assembling an appropriate project team will avoid producing the "perfect" deployment plan that is never implemented.

V. A TRAINING COURSE IN THE DEPLOYMENT OF EMERGENCY SERVICES

An important aspect of HUD's Community Development and Management Research Program is the improvement of local managerial capacity. As part of its contracts with HUD, the Institute tried to disseminate information on the tools and techniques for deployment analysis as widely as possible. In order to disseminate the information to an audience that might not have the time to read all of the relevant documents, a training course was assembled.

The course was presented to agency officials, city officials, and system analysts in several cities throughout the country. The lecture notes for the course have been published both as an instructor's manual and a student's manual:

> Jan M. Chaiken, Edward J. Ignall, and Warren E. Walker, *A Training Course In Deployment of Emergency Services*, The New York City-Rand Institute, R-1784/1-HUD (*Instructor's Manual*), R-1784/2-HUD (*Student's Manual*), both September 1975.

The *Instructor's Manual* includes notes and references to visual aids and publications that are not included in the *Student's Manual*. Instead of these, the student's manual includes blank space that the student can use for making notes and comments.

The manuals provide lesson plans and visual aids for a set of lectures so that they can be presented by anyone who already understands the subject. The instructor's manual may also be useful for persons wishing to undertake a self-directed study of deployment analysis for emergency services. Since the literature in the field is extensive, it may be difficult for someone to determine which papers are related to the subject he wishes to learn and which ones should be read before others. By following the course outline, he can determine a suitable sequence in which to study the various documents and he will have a general notion of the contents of each of them in advance.

To prepare a course from the lecture notes, it is necessary to select the lectures to be presented, and the order of presentation. Under no circumstances would all the lectures be given to one audience, since there are pairs of lectures that cover the same topic from different perspectives.

Using guest lecturers, the course could be presented in three to five days. Or, the members of a project team could share the work of learning the material in the training course notes. In this case, the material might be discussed in weekly meetings rather than being presented as formal lectures.

Potential audiences for the course include fire service administrators and planning officers, police patrol administrators and planning officers, ambulance agency personnel, city officials, operations research analysts, and mixtures of these groups.

Appendix

ADDRESSES FOR FURTHER INFORMATION

1. For documentation of any of the deployment models, copies of any of the computer programs on cards or tape, or answers to questions about the programs:

   Jan Chaiken
   The Rand Corporation
   1700 Main Street
   Santa Monica, California 90406
   (213) 393-0411

2. For copies of any reports of The New York City-Rand Institute listed in the Bibliography:

   Publications Department
   The Rand Corporation
   1700 Main Street
   Santa Monica, California 90406
   (213) 393-0411

Prices for the reports in early 1976 are as follows: 1–25 pages, $1.50; 26–50 pages, $3.00; 51–100 pages, $5.00; 101–250 pages, $7.00. California residents add 6 percent sales tax.

The reports are also available from the National Technical Information Service, where the prices differ:

   National Technical Information Service
   U.S. Department of Commerce
   Springfield, Virginia 22161

3. Research Sponsor:

   U.S. Department of Housing and Urban Development
   Alan Siegel, Director
   Hartley Campbell Fitts, Program Manager
   Office of Policy Development and Research
   Community Management and Productivity Improvement Research Division
   451 Seventh Street, S. W.
   Washington, D. C. 20410
   (202) 755-6970

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